



TECHNICAL MEMORANDUM

NON-TIME-CRITICAL REMOVAL ACTION

BEEDE WASTE OIL SITE PLAISTOW, NEW HAMPSHIRE

RESPONSE ACTION CONTRACT (RAC), REGION I

For
U.S. Environmental Protection Agency

By
Tetra Tech NUS, Inc.

EPA Contract No. 68-W6-0045
EPA Work Assignment No. 105-NARV-011T
TtNUS Project No. N4103

January 2005



TETRA TECH NUS, INC.

TECHNICAL MEMORANDUM

NON-TIME-CRITICAL REMOVAL ACTION

BEEDE WASTE OIL SITE
PLAISTOW, NEW HAMPSHIRE

RESPONSE ACTION CONTRACT (RAC), REGION I

For
U.S. Environmental Protection Agency

By
Tetra Tech NUS, Inc.

EPA Contract No. 68-W6-0045
EPA Work Assignment No. 105-NARV-011T
TtNUS Project No. N4103

January 2005



Diane M. Baxter
Project Manager



George D. Gardner, P.E.
Program Manager

**TABLE OF CONTENTS
TECHNICAL MEMORANDUM
NON-TIME-CRITICAL REMOVAL ACTION
BEEDE WASTE OIL SITE
PLAISTOW, NEW HAMPSHIRE**

<u>SECTION</u>	<u>PAGE</u>
1.0 INTRODUCTION.....	1
2.0 NTCRA WASTE EXTRACTION EVALUATION	1
3.0 OIL THICKNESS EVALUATION.....	3
4.0 OIL VOLUME EVALUATION	4
4.1 Field Evaluations of LNAPL Thickness and Characteristics	5
4.2 Estimation of LNAPL Volume Based on API/Lenhard-Parker Equations.....	8
4.3 LNAPL Volume Evaluation Summary	10

TABLES

NUMBER

- 1 Oil and Emulsion Analytical Results – Detected Compounds Only
- 2 LNAPL Emulsion Composition

FIGURES

NUMBER

- 1 Cumulative Oil and Water Extracted through September 2004
- 2 Average Oil Volume Extracted Daily – by Month
- 3 Average Daily Oil and Water Volumes by Month
- 4 Average Daily Oil Volume vs. Average Water/Oil Volume Ratio – by Month
- 5 Average Oil Thickness vs. Average Piezometric Groundwater Elevation
- 6 Estimated Oil Thickness Contours – May 2000
- 7 Estimated Oil Thickness Contours – May 2004

REFERENCES

APPENDICES

- A Total Petroleum Hydrocarbons Fingerprint Chromatograms
- B LNAPL Volume Calculations – Backup Information

1.0 INTRODUCTION

This memorandum presents the results of our evaluation of the progress of the Non-Time-Critical Removal Action (NTCRA) at the Beede Waste Oil Site through September 2004. The evaluation looked at trends in oil and water extraction by the Vacuum Enhanced Extraction (VEE) system, oil thickness measurements in system extraction wells from system start-up in February 2000 through September 2004, and the evaluations conducted in recent months to develop a better understanding of the oil plumes and oil volume remaining at the site.

This evaluation was performed by Tetra Tech NUS (TtNUS) at the request of the U.S. Environmental Protection Agency (EPA) under Contract No. 68-W6-0045, Work Assignment No. 105-NARV-011T.

2.0 NTCRA WASTE EXTRACTION EVALUATION

The VEE system commenced operation on February 21, 2000 and continues to operate. Through September 30, 2004, approximately 85,000 gallons of LNAPL and 304,000 gallons of water have been extracted and separated by the VEE system and transported off site for treatment/disposal. The overall ratio of water to oil extracted is approximately 3.6 to 1. Several charts are presented and described below to illustrate trends in waste extraction.

Figure 1 shows the cumulative oil and water volumes extracted by the system from February 2000 through September 2004. It appears that the rate of oil recovery was highest during the first several months of operation and has gradually decreased over time. The rate of water recovery was also highest during the initial months of operation. It has decreased from initial rates, but has remained relatively consistent since early 2001.

Figure 2 shows the average daily volume of oil extracted each month. The average volumes have fluctuated from month to month. The volumes appear to show a seasonal variation, with the lowest daily volumes typically occurring in the spring, then increasing gradually to a peak in the late fall, and then declining through winter to a spring low. The seasonal variations were less apparent during the first several months of operation, when extraction volumes were consistently high. Comparing average daily extraction volumes

over time, a general decreasing trend is evident, with the exception of a period from fall 2001 through spring 2002. The average extraction volumes observed during this period were higher than during the corresponding months in the previous year. This apparent increase is primarily due to more frequent overnight operation (the overnight volume is included in the volume for the day) and additional rest/recovery days during this period, which both increased the daily extraction volumes. Overnight operation was most frequent during the Fall 2001 to Spring 2002 period due to conditions in the plume, which allowed for relatively efficient operation with minimal system adjustments.

Figure 3 shows the average daily volumes of oil and water extracted each month. Trends in oil extraction are discussed above. Unlike oil extraction volumes, water extraction volumes don't exhibit clear seasonal variations. Extraction volumes, in general, appear to have decreased over time, with decreasing oil extraction volumes, but occasional periods of higher water volumes also occur.

Figure 4 shows the average water to oil extraction ratios versus the average daily volumes of oil extracted each month. This figure shows an increase in the water/oil ratios over time. In the year from October 2003 through September 2004 the overall water/oil ratio was 5.8.

It appears that the rate of oil recovery has slowed in recent months while the rate of water extraction has remained similar to earlier periods, thereby increasing the ratio of water to oil extracted. This is likely caused by the decrease in oil thickness in the plumes resulting from extraction of approximately 85,000 gallons of oil. As the oil thickness in the plumes and extraction wells decreases it becomes more difficult to extract the oil from the water surface without extracting more water. As the oil thickness has decreased, system operation has required more frequent well/drop-tube adjustments to optimize system operation, extracting as much oil and as little water as possible. The drop in oil extraction rates and rise in water/oil ratios has occurred despite more intensive monitoring and adjustment. However, changes in operation schedule and staffing in recent months appear to have helped increase extraction efficiency, as demonstrated by the lower water/oil ratios observed from June through September 2004.

3.0 OIL THICKNESS EVALUATION

Changes in oil thickness in the VEE system extraction wells were evaluated as an indicator of NTCRA progress. It is generally accepted that the measured oil thickness in a well does not correlate exactly to the thickness in the aquifer formation. Factors that may contribute to the disparity include differences in capillary properties in the formation, the filter pack surrounding the well and the well itself, and fluctuations in the water table. Despite these factors, the measured thicknesses can be used to draw some conclusions about NTCRA progress and status.

Evaluation of site data indicates that the measured oil thicknesses in system extraction wells vary as the groundwater rises and falls. In general, the measured oil thickness in the wells is greatest when the potentiometric groundwater elevations are the lowest and visa versa (see Figure 5). This is consistent w/ conceptual model of LNAPL behavior in the subsurface as described in literature (API, 1999). Because of this relationship between measured oil thickness and groundwater elevation, when evaluating changes in oil thickness it is necessary to compare time periods that have similar groundwater elevations. Four time periods (April-May 2000, 2001, 2003, 2004) representing the highest observed groundwater elevations were selected for evaluation. It is assumed that the oil thickness measured at these times may represent the lowest exaggeration and best correlation between the measured oil thickness in wells and the actual mobile oil thickness in the subsurface. Comparing the average oil thicknesses for these periods on Figure 5, there appears to be an overall trend of decreasing oil thickness at the site from April-May 2000 to May 2004.

During each monitoring event shown on Figure 5, all 143 VEE system extraction wells were monitored with an electronic oil/water interface probe to determine the groundwater elevation and oil thickness. For the monitoring periods compared, the number of wells in nearly every oil thickness bracket has decreased over time, illustrating an overall decrease in oil thickness at the site. Only the number of wells with oil less than 0.25 feet thick has increased significantly from April-May 2000. This thickness interval now constitutes the majority of wells. The relatively consistent number of wells with oil present (greater than 0 ft) indicates that the overall areal extent of the plumes has probably not changed significantly.

Oil Thickness	Number of Wells With Stated Oil Thickness			
	Apr-May-00	May-01	May-03	May 2004
5 ft. to 6 ft.	1	0	0	0
4 ft. to 5 ft.	1	0	0	0
3 ft. to 4 ft.	3	2	1	0
2 ft to 3 ft.	6	2	1	2
1.5 ft. to 2 ft.	5	3	4	0
1 ft. to 1.5 ft.	9	6	2	2
0.5 ft. to 1 ft.	24	17	14	11
0.25 ft. to 0.5 ft.	17	16	19	10
>0 ft to 0.25 ft	27	59	53	76
Total > 0 ft	93	105	94	101

The oil thickness monitoring data were used to prepare estimated oil thickness contour figures for April-May 2000 and May 2004 monitoring periods (see Figures 6 and 7). Comparison of the figures shows that the thickness of the oil plumes has decreased over time, but the areal extent of the plumes doesn't appear to have changed significantly. The decrease in oil thickness is clearly illustrated by the decrease in the size of areas with oil thickness greater than 0.5 feet. Changes in overall plume size are more difficult to assess because several wells show no measurable oil during some periods and then have a measurable thickness in some subsequent periods. The contours have been drawn to show these wells and the surrounding areas as having no oil when no measurable oil was observed; however, the presence of oil in these areas during intervening periods indicates that the plume is likely continuous in these areas, but is very thin (a sheen too thin to measure) or is immobilized in the soil pores during some monitoring periods. The plumes do not appear to be actively migrating. The overall shapes of the plumes have remained relatively consistent over time.

4.0 OIL VOLUME EVALUATION

Estimating the volume of mobile or recoverable oil present in the subsurface at the Beede Waste Oil site is complicated by many factors including those inherent with any LNAPL system, such as the seasonal fluctuation of oil thickness in monitoring wells and the lack of correlation between measured and actual oil thickness in the subsurface. Evaluating the LNAPL system at the Beede site is further complicated by the heterogeneous composition and characteristics of oils across the site, the presence of emulsion in some wells, the presence of

the oil in at least four distinct geologic units, and measurement difficulties for most of the oils present. TtNUS performed two types of evaluations to develop a better understanding of the oil remaining in the subsurface at the site. These are described below.

4.1 Field Evaluations of LNAPL Thickness and Characteristics

Three types of field evaluations were performed by TtNUS to assist in better understanding the nature and extent of LNAPL remaining at the site. This section describes the evaluations performed.

Oil and Emulsion Thickness Measurement Evaluation

Obtaining an accurate measurement of the LNAPL thickness in wells at the site is difficult because of the viscosity of the oil and presence of emulsion in some wells. When using a standard electronic interface probe, the viscous oil coats the probe and makes it difficult to detect the oil/water interface; the presence of emulsion beneath the oil makes it difficult to clearly identify the bottom of the oil or the top of the water because the emulsion registers on the probe as a fast beeping tone between those of oil and water (the frequency of the beep can vary to sound similar to an oil or water tone).

To address the measurement difficulty, TtNUS used a custom-designed bailer to collect relatively undisturbed samples of the entire LNAPL column in several monitoring wells. The content of the bailer was observed immediately upon collection and after settling to identify the presence of distinct layers. The thickness of the fluids in the bailers were measured and compared with thickness measurements taken using an LNAPL interface probe to determine the accuracy of the well measurements.

The following conclusions were drawn from the bailer samples and measurements:

- A distinct emulsion layer was identified below the oil layer in several wells. The emulsion layer was generally a distinctly lighter colored layer of a different consistency than the oil.

- In some wells, the LNAPL column consisted of 3 or more different layers (multiple oil and/or emulsion layers).
- The interface probe appears to accurately detect the presence of emulsion in most cases, but does not seem to provide accurate measurements of emulsion thickness.
- Oil thickness measurements taken with the probe generally correlated well with the thickness in the bailer, but emulsion thickness measurements did not correlate well.

Waste Characterization

Oil and emulsion samples from five wells (EW-23, EW-34, EW-94, EW-109, and EW-110 – see Figures 6 and 7) were sent to an off-site laboratory for chemical and physical characterization to determine the content and characteristics of the oil and emulsion and to determine the relationship between the oil and the emulsion. The samples were analyzed for VOCs, PCBs, TPH/petroleum hydrocarbon fingerprinting, density, and viscosity. In addition, the emulsion samples were physically separated to determine percent oil, water, and sediment. The analytical results for the oil and emulsion are presented on Tables 1 and 2. TPH fingerprint chromatograms for the oil and emulsion samples and diesel fuel and motor oil standards are presented in Appendix A. The following conclusions were drawn from the waste analyses.

- The oil and emulsion samples from all 5 wells have TPH fingerprint patterns typical of a mix of No. 2 diesel fuel and motor oil, but the mixtures vary across the site. The two samples from the lagoon plume appear to have a greater fraction of motor oil, whereas the samples from the UST plume appear to have a greater fraction of diesel fuel. None of the samples have identical fingerprints.
- The fingerprint patterns from the oil and emulsion samples from the same location were similar.

- The chemical constituents of the NAPLs are fairly similar across the site, but occur in varying concentrations. The resulting NAPLs exhibit very different physical properties.
- The emulsion samples typically have chemical constituents similar to the oil samples from the same wells, but sometimes in markedly different concentrations. Most notable was that the PCB concentrations in all emulsion samples were nearly double the PCB concentrations in the oil sample from the same well.
- The oil densities were similar (0.8745 to 0.8863 g/ml); the emulsion densities showed greater variation (0.888 to 0.9646 g/ml). The emulsion samples were heavier than the corresponding oil samples.
- Oil viscosities ranged from 53.93 to 136.3 CTS. Emulsion viscosities ranged from 148.3 to 2196 CTS. The emulsion samples were more viscous than the corresponding oil samples.
- The emulsion appears to be derived from the oil in the same area. However, it is not clear whether the emulsion is a settled component of the original waste oil mixture (possibly a heavier fraction with more suspended solids), whether it is created in the subsurface as a result of naturally occurring subsurface conditions such as biological activity, or whether it is created in the wells (and possibly the surrounding area) as a result of the vacuum extraction process.
- The extent of the emulsion presence in the subsurface is uncertain because its presence has only been noted sporadically at most wells where it has been detected. It appears to be present most consistently in the areas north of soil stockpile 5A (wells 99 – 101, 109, 110, 115) and in/near surface water retention pit 2 (SWRP 2) (wells 124, 131, 137, 138). However, even in these wells it has not been detected during every monitoring period.
- The properties of the emulsion, particularly the high viscosity, may further complicate LNAPL extraction if it is present on a large scale because it will likely be less mobile and more difficult to remove from the soil pore spaces.

Monitoring Well and Subsurface Oil Thickness Relationship

TtNUS conducted product recovery tests in several wells to determine whether a relationship could be established between the observed thickness in the wells and the actual thickness in the aquifer. The tests were conducted using a procedure adapted from methods presented by Hughes, et al. (1988), and Aral and Liao (2000). These methods involve evacuating the LNAPL from a well and monitoring and plotting its recovery to identify the inflection point, which corresponds to the LNAPL entry point – or bottom of the mobile LNAPL layer in the formation. The LNAPL thickness measured at the inflection point is used to estimate the actual LNAPL thickness in the aquifer. In theory, the LNAPL recovery rate will remain constant until air/LNAPL interface in the well rises to the LNAPL entry point, and will then steadily decrease as the LNAPL surface in the well rises above the entry point. The plot of the LNAPL thickness during recovery is evaluated to identify the inflection point.

Product recovery tests were attempted in several wells (EW-22, EW-26, EW-29, EW-86, EW-116, and EW-110). The test results at all wells were determined to be inconclusive because either the inflection point could not be identified or the recharge curve did not fit the profile required to estimate product thickness using this method (initial constant recharge rate followed by a decreasing recharge rate). The principal problems that impeded successful tests were: monitoring difficulties due to the viscous oil and emulsion, slow recovery, and lack of overnight monitoring of recovery. Monitoring difficulties in combination with slow recovery were the most significant problem. In some cases, due to slow recovery and viscous oil, the process of measuring the oil thickness removed much or all of the product that had recovered since the last measurement.

4.2 Estimation of LNAPL Volume Based on API/Lenhard-Parker Equations

TtNUS attempted to estimate the volume of mobile LNAPL remaining at the site using equations and methods provided in the following peer-reviewed publications: Free-Product Recovery of Petroleum Hydrocarbon Liquids, API, 1999; and *Estimation of Free Hydrocarbon Volume from Liquid Levels in Monitoring Wells*, Lenhard and Parker, 1990. These methods are based on the premise that LNAPL is part of a multi-phase saturation system with unique responses based on both specific soil types and LNAPL properties. In theory, in the

subsurface, each LNAPL will have a distinct saturation profile based on the LNAPL type and subsurface lithology. Accurate estimations of LNAPL volume in the subsurface are dependent upon understanding the site-specific capillary pressure response curve for each plume and distinct lithology. In other words, a distinct capillary pressure response curve should be developed for each area of the plume where the LNAPL characteristics and/or lithology changes.

For many sites, the LNAPL type is one consistent type, and may only occur over one or two distinct lithologies. However, at the Beede Waste Oil site, several LNAPLs occur simultaneously over at least four distinct lithologies (sand, fine sand, gravelly sand, and fill). Though the variance of LNAPL type itself may not significantly affect the capillary pressure curve, it is important to consider many site-specific capillary pressure curves in representative portions of the plumes in order to ensure that an accurate calculation is performed. At a bare minimum, one capillary pressure curve should be developed for each lithology.

Site-specific data is always recommended. However, it is typically not available, as in this case. In absence of site-specific data, input parameters were selected from literature values based on site-specific soil types, conductivity parameters, and LNAPL properties. Since sand is the dominant soil type, an average sand lithology was selected. Because sand has a wide range of potential properties, the resulting range of potential literature values for the capillary fit parameters was quite large, usually encompassing the full spectrum of legitimate values. Average values were selected as representative inputs (see attachment for selected values).

Calculations were made with the TtNUS LNAPL volume estimation routine that explicitly solves for the unit volume in soil and then uses the affected area to determine the total volume. Two test cases were also run, one with API's volume estimation routine (using same input) as a check and one example with modified input parameters. All three sets of calculations resulted in an obvious gross under-estimation of the total volume of oil present at the site. The general conclusion from this evaluation is that this methodology, although applicable to the problem at the site, could only be employed effectively here if a large amount of site-specific data were available. Selecting alternative input values from published sources would not provide a greater degree of certainty because the range of capillary fit parameters for sands is very large, the range of LNAPL characteristics varies widely across the site, and the possible matrix

of LNAPL/ lithology combinations is too large to reasonably derive average conditions for the site.

Collecting site-specific data to develop more representative capillary pressure curves could improve the accuracy of the volume calculations. However, since the number of lithologies and wide range of LNAPL present (including various types of oil and emulsion) create numerous possible lithology/LNAPL combinations, a large amount of site-specific data (i.e. specialized analysis of LNAPL samples and undisturbed cores of the LNAPL saturated soils from many locations within the plumes) would be required to provide a reasonable degree of certainty in the accuracy of the calculations. To provide the highest degree of certainty, all possible combinations of LNAPL and lithology would have to be sampled. This scale of investigation is not recommended because it is unlikely to provide benefits commensurate with its cost.

4.3 LNAPL Volume Evaluation Summary

In conclusion, field evaluations and laboratory characterization of the LNAPL at the site confirms that the LNAPL plumes at the site are comprised of oils and emulsions with widely varying chemical and physical properties. The physical properties of the LNAPLs make it difficult to accurately measure their thickness in site monitoring wells. Additionally, the varying properties cause the LNAPLs to have different behaviors in the subsurface. The presence of the LNAPL in several different geologic units further complicates the situation, as LNAPL will behave differently in different lithologies. As a result of all of these factors, the LNAPL saturation profiles of each LNAPL in each of the geologic unit at the site will differ.

Because of the complexity of the LNAPL plumes and lithology at the Beede Waste Oil site and the inherent difficulties in relating widely varying well thickness measurements to actual LNAPL volume in the subsurface, it is not possible, with the available data, to develop LNAPL volume estimates for the site with a high degree of certainty. However, based on the significant LNAPL thickness still routinely present in many wells and the continuing ability of the VEE system to extract an average of nearly 50 gallons of LNAPL daily, it appears that a significant volume of recoverable LNAPL remains at the site.

TABLES

TABLE 1
OIL AND EMULSION ANALYTICAL RESULTS - DETECTED COMPOUNDS ONLY
TECHNICAL MEMORANDUM
BEEDE WASTE OIL SITE
PLAISTOW, NEW HAMPSHIRE

Sample Number	BWO-OIL- EW23	BWO-EMUL- EW23	BWO-OIL- EW34	BWO-EMUL- EW34	BWO-OIL- EW94	BWO-OIL- EW109	BWO-EMUL- EW109	BWO-OIL- EW110	BWO-EMUL- EW110
Plume Designation	Fmr. Lagoon	Fmr. Lagoon	Fmr. Lagoon	Fmr. Lagoon	UST	UST	UST	UST	UST
Date Sampled	7/27/2004	7/27/2004	7/26/2004	7/26/2004	7/26/2004	7/27/2004	7/26/2004	7/26/2004	7/26/2004
QC Identifier	None	None	None	None	None	None	None	None	None
Volatile Organic Analysis (UG/KG)									
1,1,1-Trichloroethane	11000	7300	37000	9500	890 J	2500 U	2500 U	2500 U	2500 U
1,1,2-Trichloro-1,2,2-trifluoroethane	2200 J	1400 J	2200 J	500 J	1700 J	2500 U	2500 U	2500 U	2500 U
1,1,2-Trichloroethane		2500 U		2500 U			3300		2500 U
1,1-Dichloroethane	440 J	290 J	360 J	2500 U	1500 J	2500 U	2500 U	2500 U	2500 U
1,1-Dichloroethene	1800 J	780 J	5400	1300 J	2500 U	2500 U	2500 U	2500 U	2500 U
1,2,4-Trichlorobenzene	430 J	260 J	440 J	2500 U	1500 J	2500 U	820 J	1300 J	2500 U
1,2-Dichlorobenzene	12000	6600	17000	3900	17000	2500 U	2100 J	9400	2500 U
1,2-Dichloroethane		2500 U		330 J			2500 U		2500 U
1,3-Dichlorobenzene	1200 J	690 J	1300 J	330 J	1700 J	2500 U	520 J	1100 J	2500 U
1,4-Dichlorobenzene	2900	1800 J	3300	850 J	5600	2500 U	1500 J	3000	2500 U
2-Butanone	2100 J	1500 J	2500 U	2100 J	1900 J	2500 U	1100 J	1700 J	2500 U
2-Hexanone	12000		2500 U		2500 U	2500 U		2500 U	
Acetone	2500 U	2500 U	2500 U	2500 U	950 J	2500 U	260 J	650 J	2500 U
Benzene	520 J	340 J	19000	5800	1200 J	2500 U	2500 U	2500 U	2500 U
Chloroethane	2500 U		2500 U		260 J	2500 U		2500 U	
cis-1,2-Dichloroethene	6100	4200	38000	13000	2500 U	2500 U	2500 U	2500 U	2500 U
Cyclohexane	2500 U		2500 U		2500 U	2500 U		1900 J	
Dibromochloromethane		860 J		2500 U			2500 U		2500 U
Ethylbenzene	35000	22000	110000 *	30000	36000	2700	1500 J	11000	9800
Isopropylbenzene	8000	4300	19000	4800	10000	1500 J	680 J	3800	2100 J
Methylcyclohexane	12000	6700	39000	9900	64000 *	9700	4000	20000	4500
Styrene	3500	2100 J	11000	3000	5200	2500 U	550 J	2200 J	2500 U
Tetrachloroethene	2100 J	1300 J	4400	1200 J	1200 J	790 J	2500 U	590 J	350 J
Toluene	18000	11000	280000 *	54000 *	48000	2100 J	1100 J	5400	7100
Total Xylenes	150000 *	120000	740000 *	140000 *	280000 *	53000	28000	110000	79000
Trichloroethene	2500 U	2500 U	14000	4200	2500 U	2500 U	2500 U	2500 U	2500 U
PCB Analysis (UG/KG)									
Aroclor-1242	20000	43000	23000	42000	21000	28000	68000	34000	65000
Aroclor-1260	9000	17000	7200	13000	22000	28000	66000	25000	46000
Extractable Total Petroleum Hydrocarbon Analysis (MG/KG)									
Total Petroleum Hydrocarbons	640000	790000	680000	620000	940000	650000	710000	740000	760000
Wet Chemistry Analysis									
Density @25 deg C	0.8863	0.888	0.8808	0.9646	0.8745	0.8866	0.9415	0.8777	0.9473
Kinematic Viscosity @25 deg C	136.3	148.3	94.11	2196	53.93	118.4	626.7	70.96	667.1

TABLE 2
LNAPL EMULSION COMPOSITION
TECHNICAL MEMORANDUM
BEEDE WASTE OIL SITE
PLAISTOW, NEW HAMPSHIRE

EPA ID	WELL ID	PERCENT BY VOLUME AFTER SEPARATION*			
		OIL	EMULSION	SEDIMENT	WATER
D13224	EW-23	9.0%	50.7%	35.8%	4.5%
D13222	EW-34	8.1%	0.0%	87.5%	4.4%
D13218	EW-109	6.1%	31.7%	37.9%	24.3%
D13220	EW-110	7.7%	33.4%	28.8%	30.0%

* Separation by centrifuge (3 minutes @ 3000 rpm + 3 minutes @ 4000 rpm)
plus gravity settling.

FIGURES

FIGURE 1
CUMULATIVE OIL AND WATER EXTRACTED THROUGH SEPTEMBER 2004
BEEDE WASTE OIL SITE NTCRA

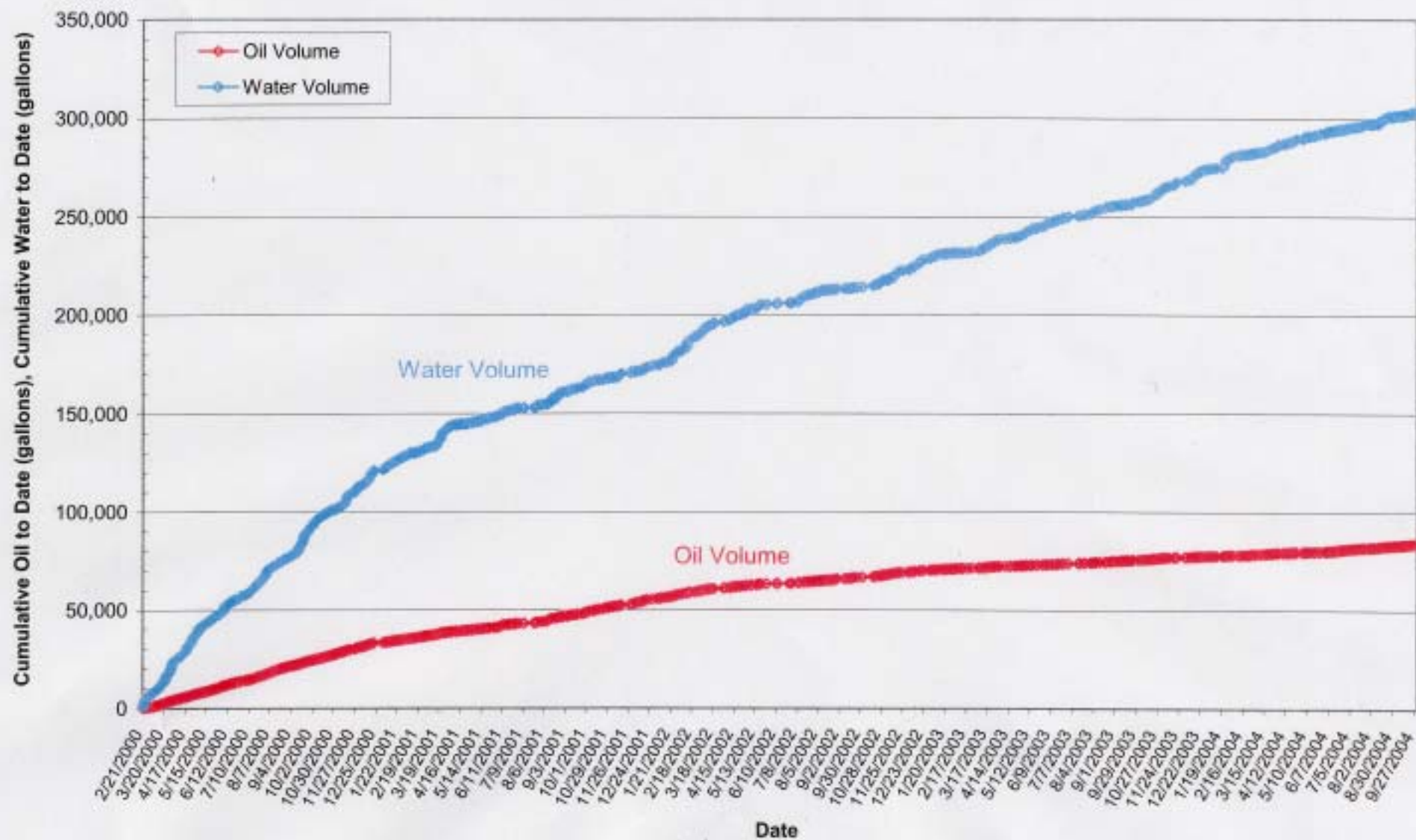


FIGURE 2
AVERAGE OIL VOLUME EXTRACTED DAILY - BY MONTH
BEEDE WASTE OIL SITE NTCRA

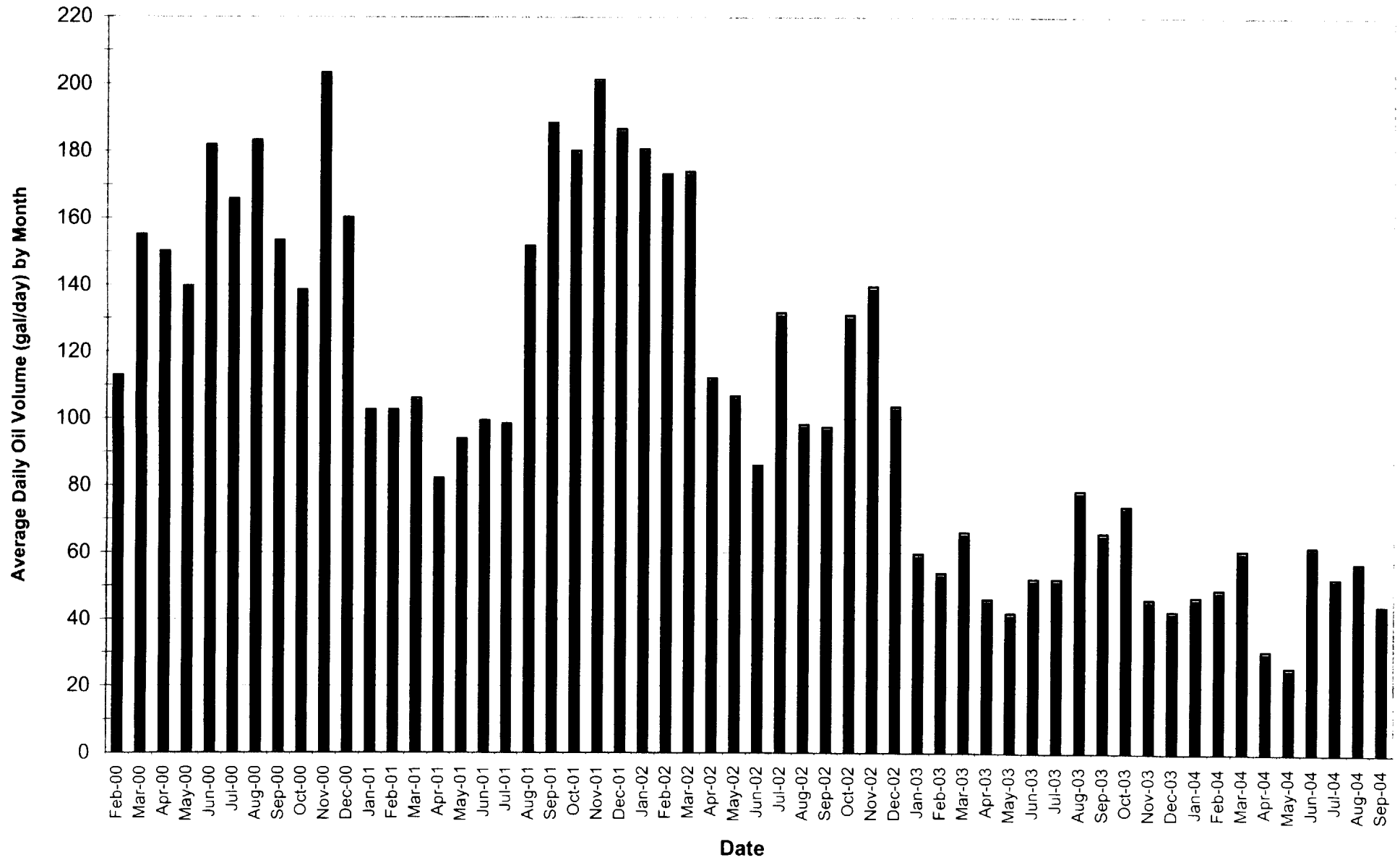


FIGURE 3
AVERAGE DAILY OIL AND WATER VOLUMES BY MONTH
BEEDE WASTE OIL SITE NTCRA

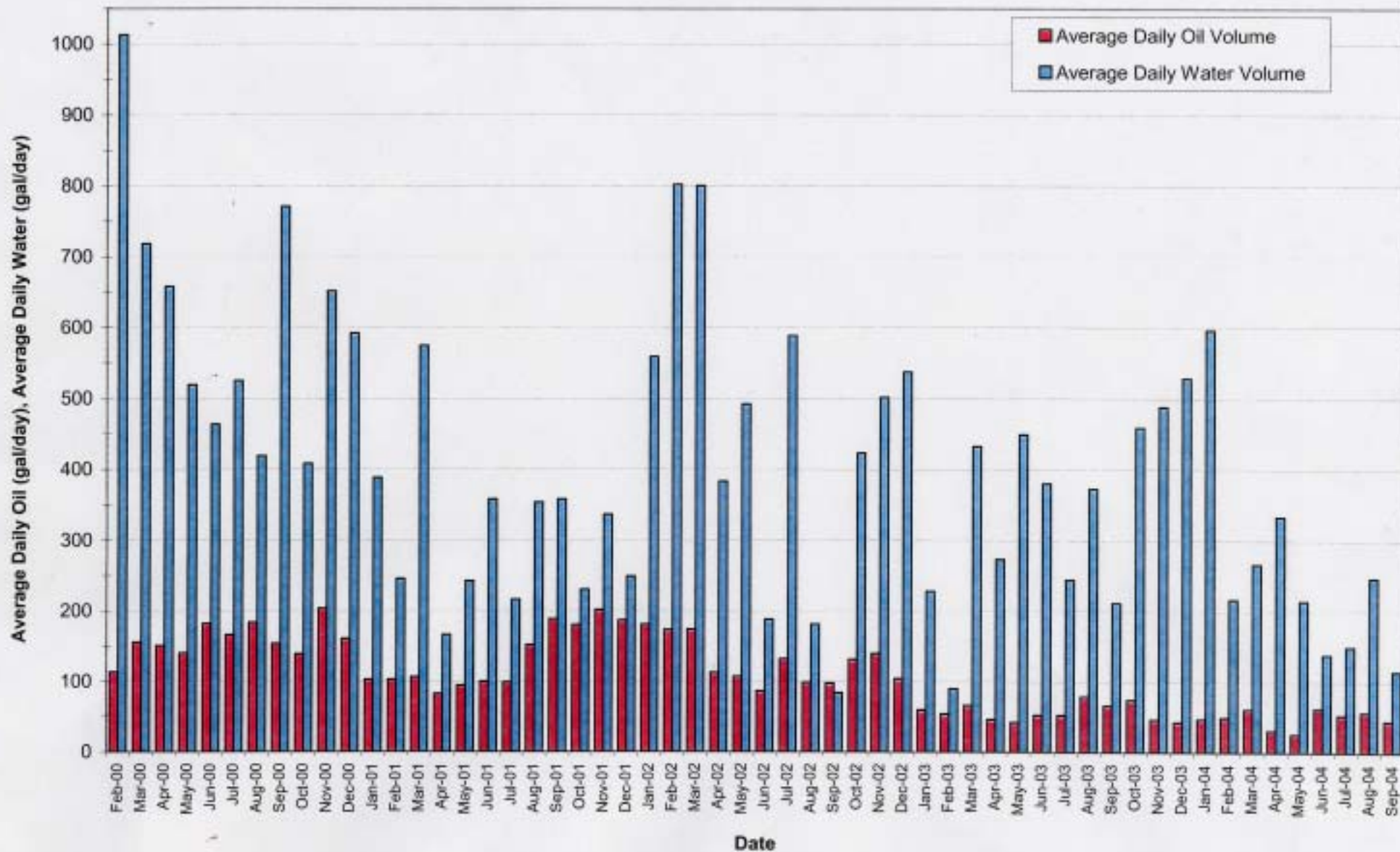


FIGURE 4
AVERAGE DAILY OIL VOLUME VS AVERAGE WATER/OIL VOLUME RATIO - BY MONTH
BEEDE WASTE OIL SITE NTCRA

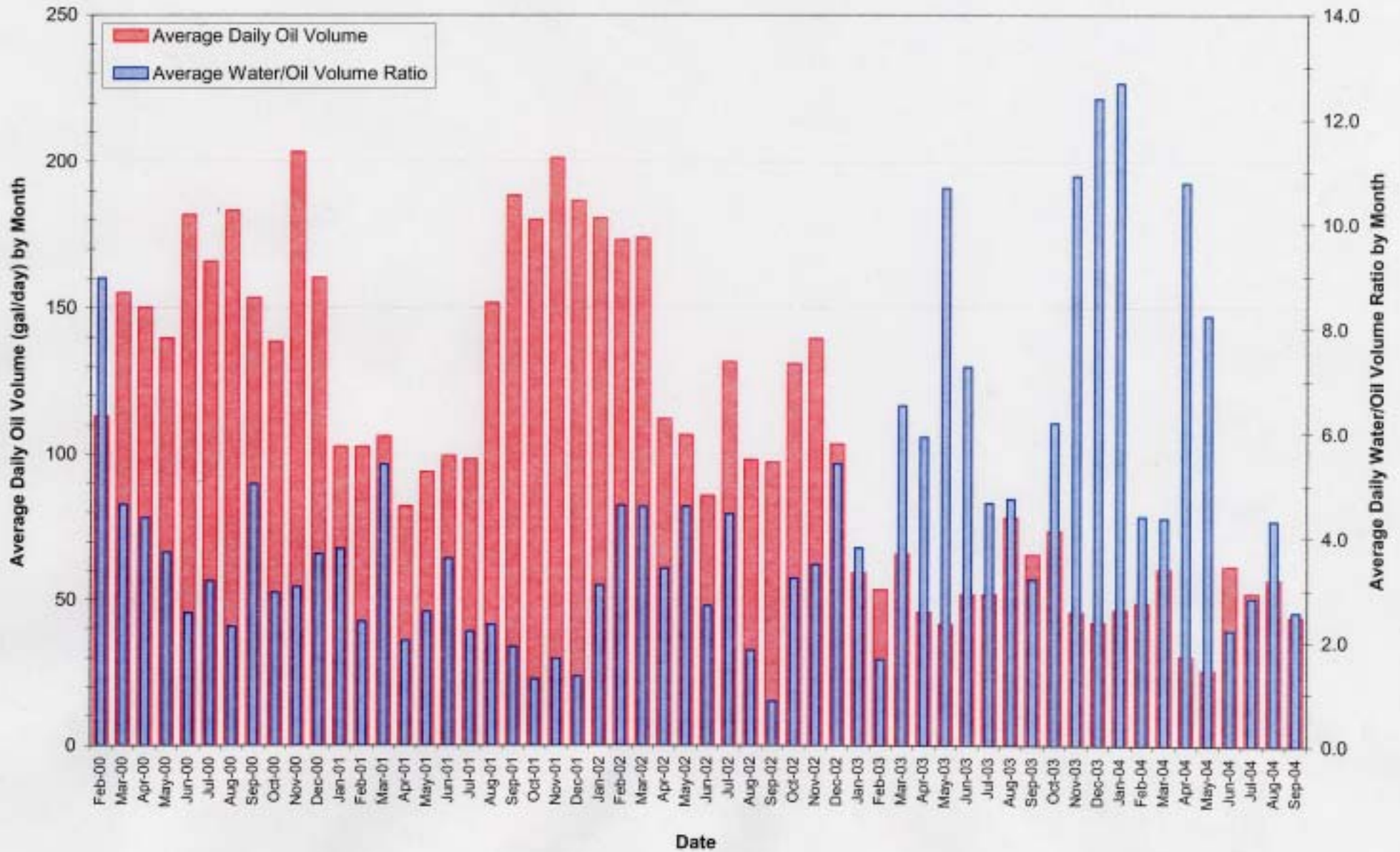
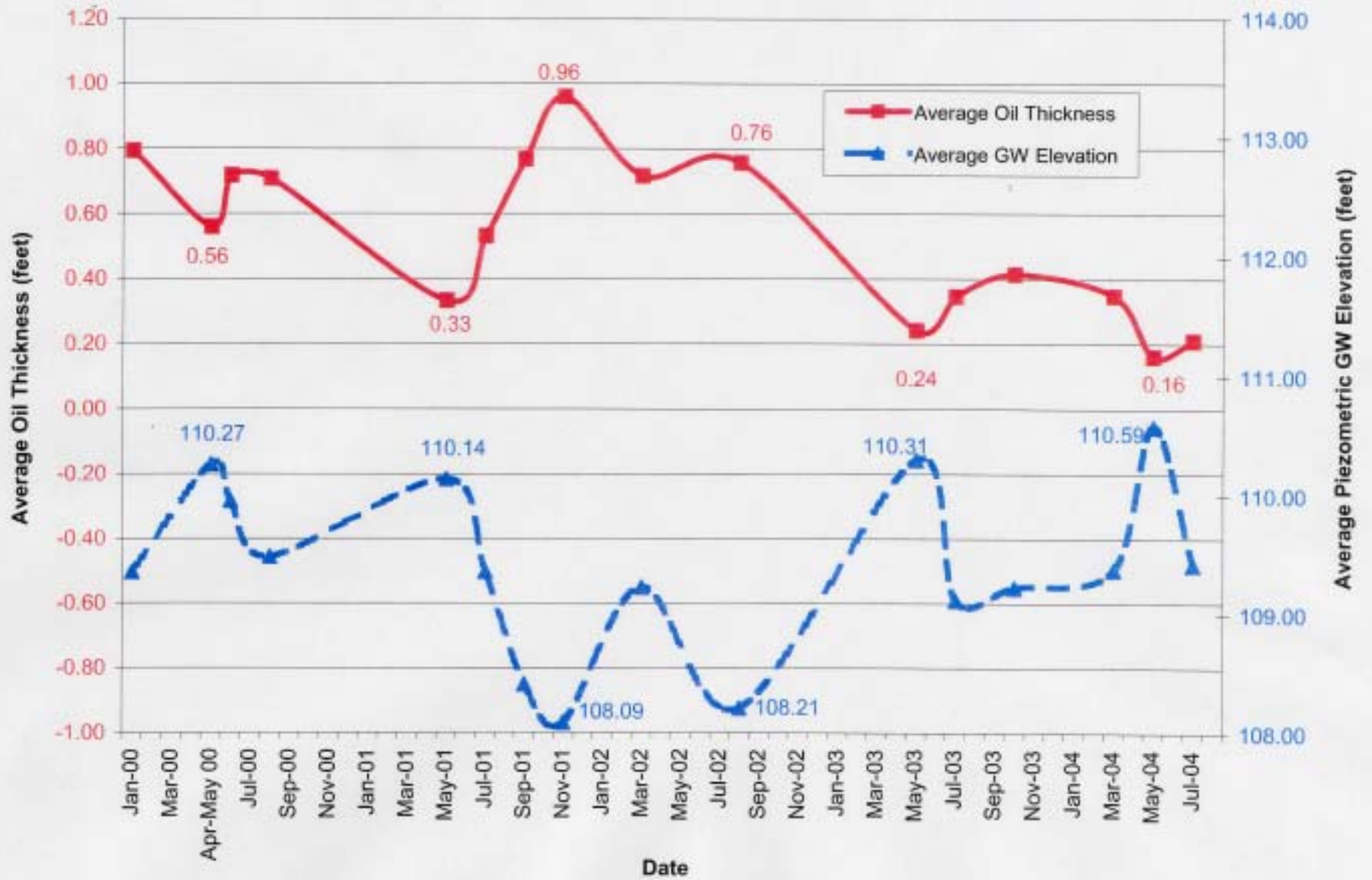
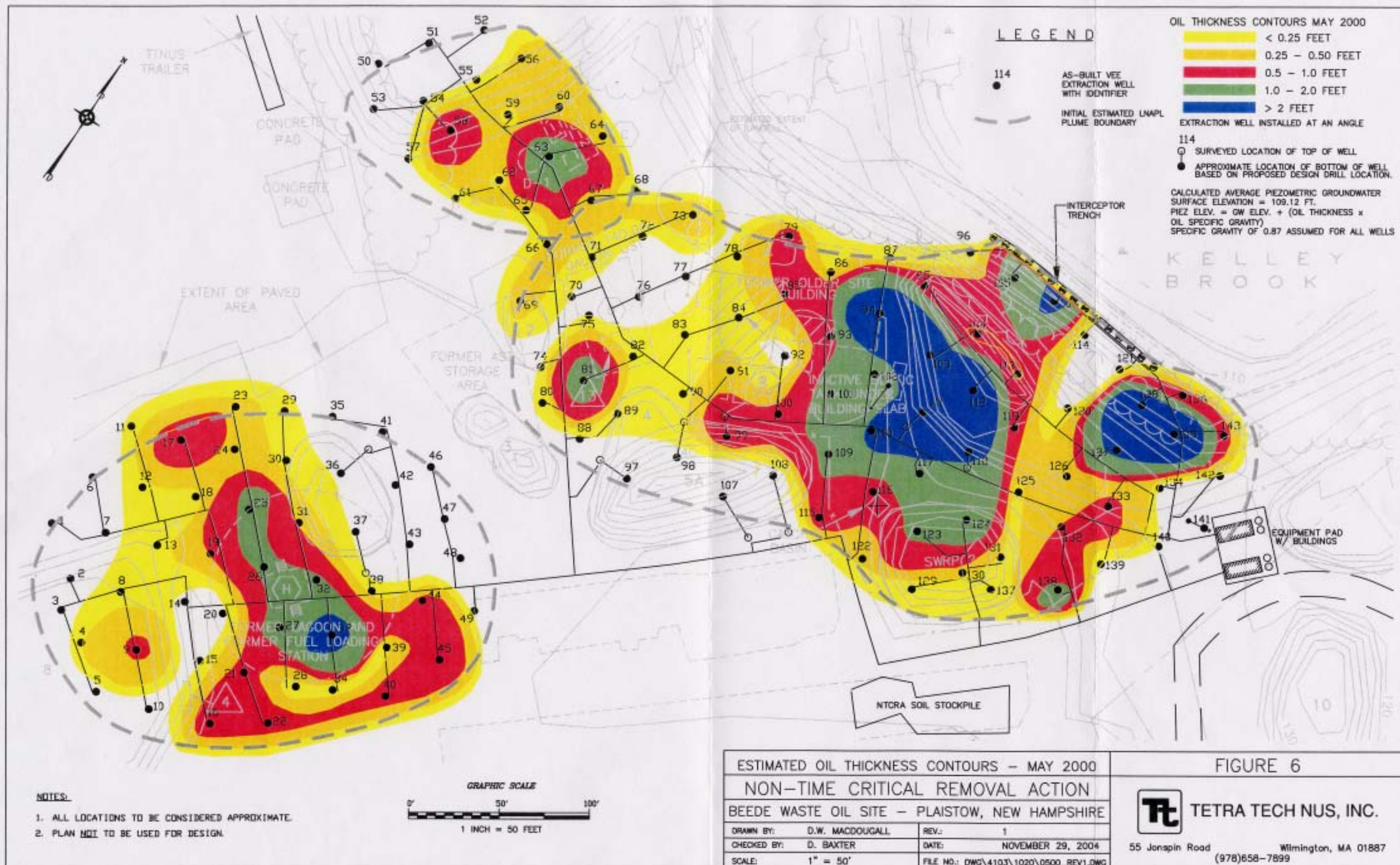
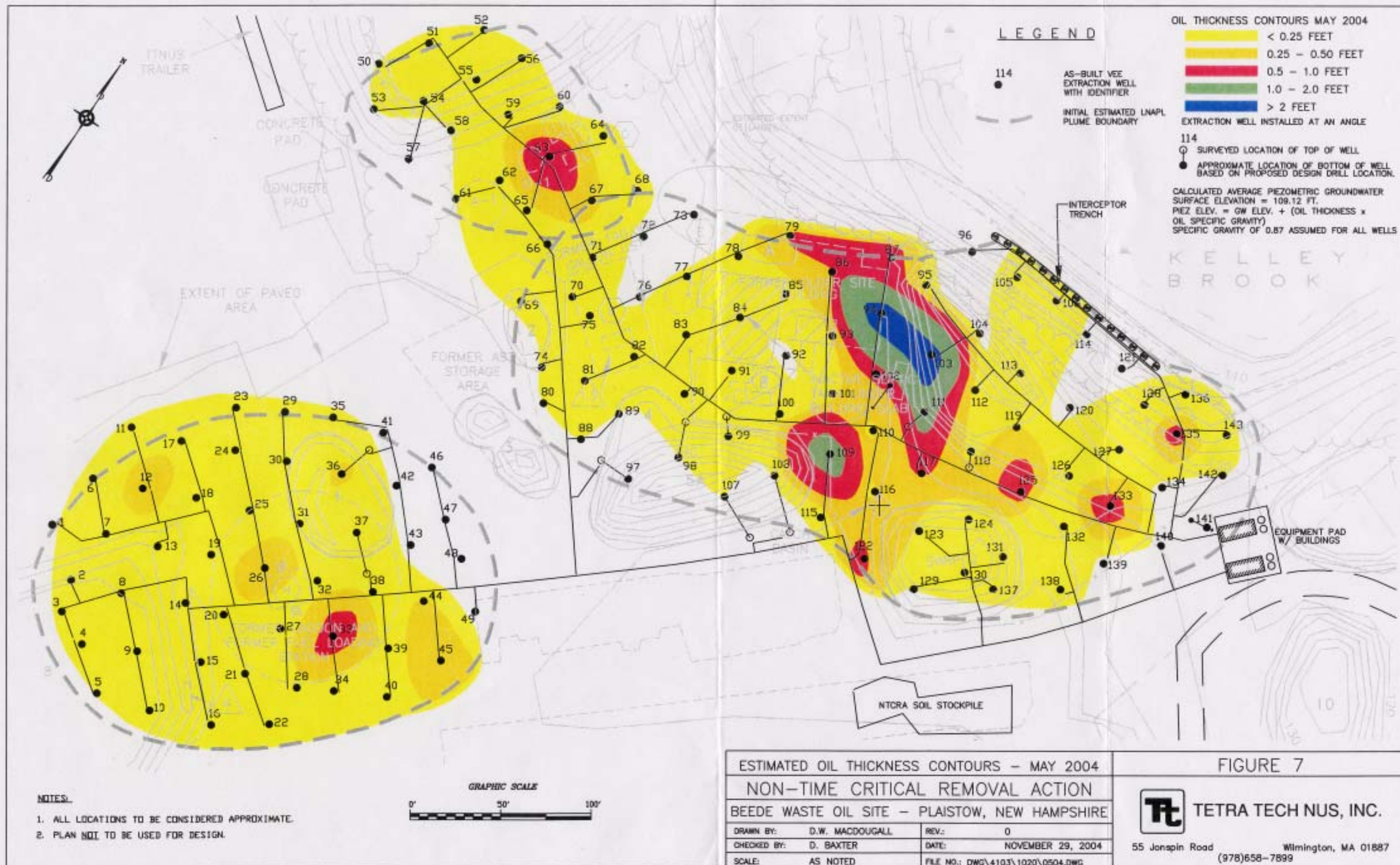


FIGURE 5
AVERAGE OIL THICKNESS VS AVERAGE PIEZOMETRIC GROUNDWATER ELEVATION
BEEDE WASTE OIL SITE NTCRA







REFERENCES

REFERENCES

American Petroleum Institute, 1999. Free-Product Recovery of Petroleum Hydrocarbon Liquids, June 1999. American Petroleum Institute Publication Number 4682.

American Petroleum Institute, 2003. Models for Design of Free-Product Recovery Systems for Petroleum Hydrocarbon Liquids, August 2003. American Petroleum Institute Publication Number 4729.

Aral, Mustafa M. and Liao, Boshu, 2000. *LNAPL Thickness Interpretation Based on Bail-Down Tests*. Groundwater, Vol. 38, No. 5, September–October, 2000.

Hughes, John P., Clay R. Sullivan, and Ronald E. Zinner, 1992. *Two Techniques for Determining the True Hydrocarbon Thickness in an Unconfined Sandy Aquifer*. Proceedings of the Conference on Petroleum Hydrocarbons and Organic Chemicals in Groundwater: Prevention, Detection, and Restoration, November 1988.

Lenhard, R.J. and Parker, J.C. 1990. *Estimation of Free Hydrocarbon Volume from Liquid Levels in Monitoring Wells*, 1990. Groundwater, January-February 1990.

APPENDIX A

**TOTAL PETROLEUM HYDROCARBONS
FINGERPRINT CHROMATOGRAMS**

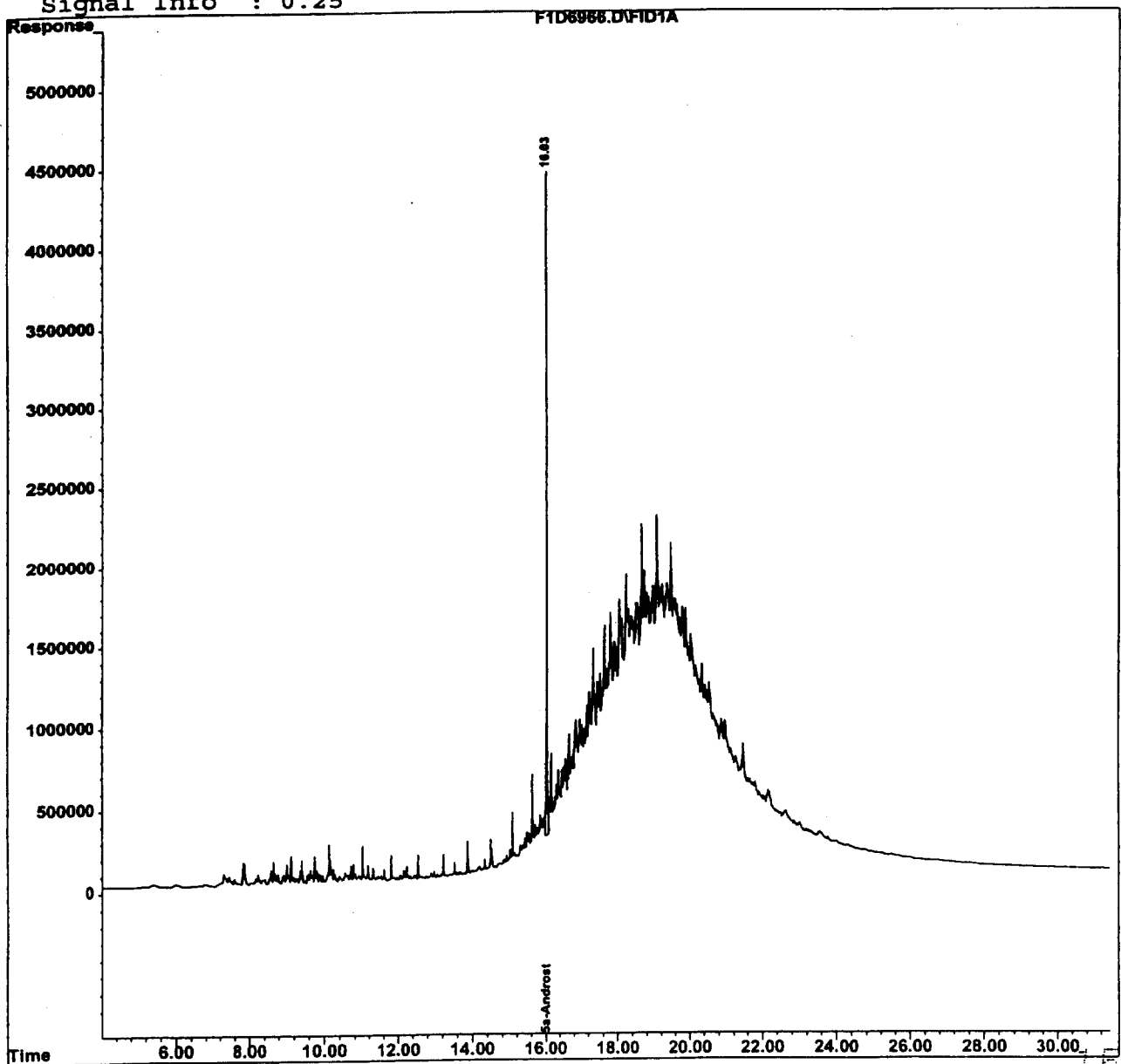
Quantitation Report

Data File : C:\HPCHEM\1\DATA\AUG04\040819\F1D6966.D Vial: 8
Acq On : 8-19-04 15:53:00 PM Operator: TT
Sample : C0809-11B X20 Inst : F1
Misc : Multiplr: 1.00
IntFile : AUTOINT1.E
Quant Time: Aug 19 16:32 19104 Quant Results File: ET0304F.RES

Quant Method : C:\HPCHEM\1\QMETHODS\ET0304F.M (Chemstation Integrator)
Title : TPH-GC, Fuel ID, DRO
Last Update : Fri Aug 13 08:50:23 2004
Response via : Multiple Level Calibration
DataAcq Meth : ETPH-B.M

D13223
Bw0-01L-EW23

Volume Inj. : 1
Signal Phase : DB-5MS
Signal Info : 0.25



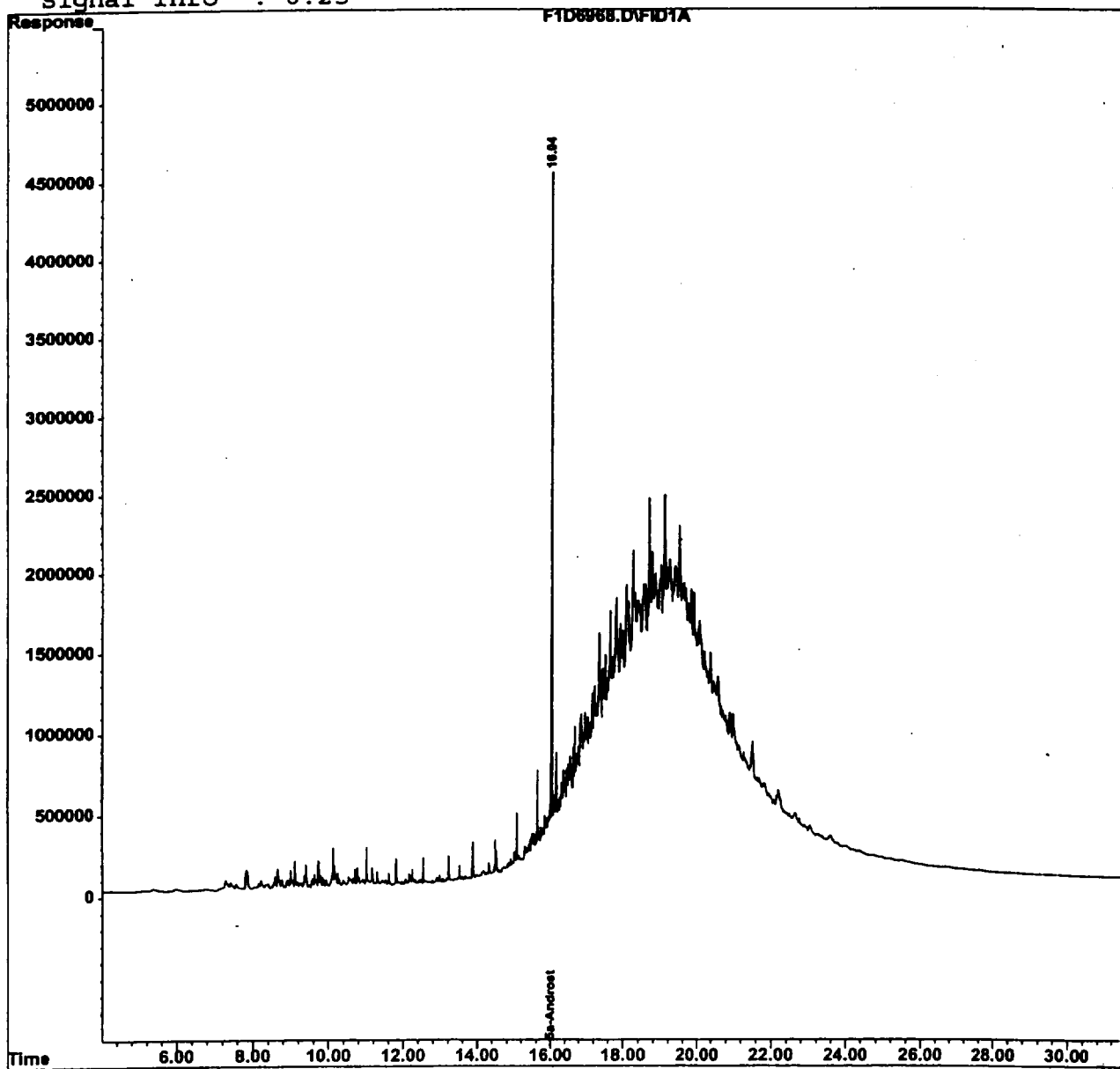
Quantitation Report

Data File : C:\HPCHEM\1\DATA\AUG04\040819\F1D6968.D Vial: 9
Acq On : 8-19-04 16:31:07 PM Operator: TT
Sample : C0809-12B X20 Inst : F1
Misc : Multiplr: 1.00
IntFile : AUTOINT1.E
Quant Time: Aug 20 8:44 19104 Quant Results File: ET0304F.RES

Quant Method : C:\HPCHEM\1\QMETHODS\ET0304F.M (Chemstation Integrat
Title : TPH-GC, Fuel ID, DRO
Last Update : Fri Aug 13 08:50:23 2004
Response via : Multiple Level Calibration
DataAcq Meth : ETPH-B.M

D13224
BWO-EMUL-EN

Volume Inj. : 1
Signal Phase : DB-5MS
Signal Info : 0.25



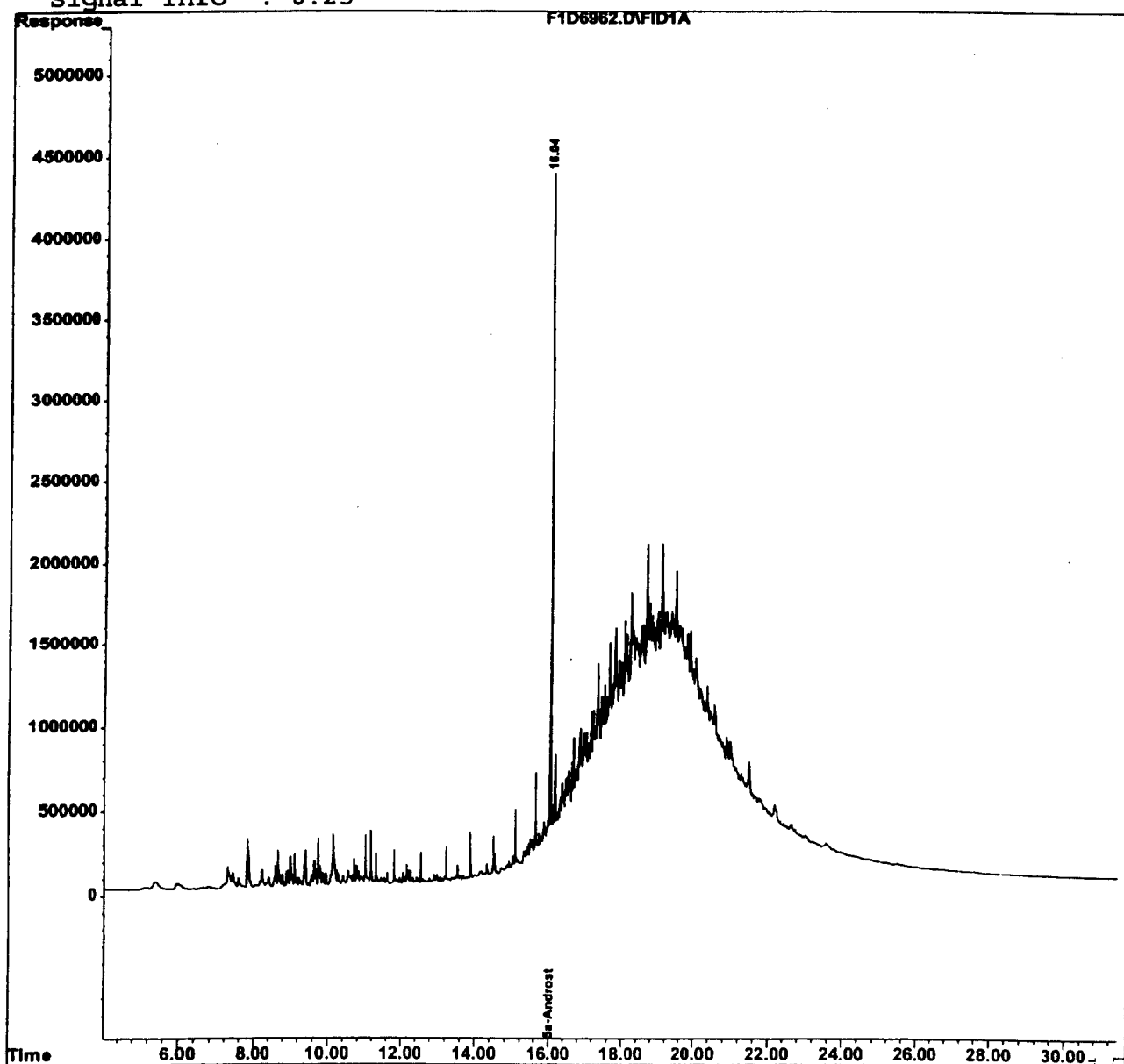
Quantitation Report

Data File : C:\HPCHEM\1\DATA\AUG04\040819\F1D6962.D Vial: 6
Acq On : 8-19-04 14:36:25 PM Operator: TT
Sample : C0809-09B X20 Inst : F1
Misc : Multiplr: 1.00
IntFile : AUTOINT1.E
Quant Time: Aug 19 15:32 19104 Quant Results File: ET0304F.RES

Quant Method : C:\HPCHEM\1\QMETHODS\ET0304F.M (Chemstation Integrator)
Title : TPH-GC, Fuel ID, DRO
Last Update : Fri Aug 13 08:50:23 2004
Response via : Multiple Level Calibration
DataAcq Meth : ETPH-B.M

D13221
BWO-01L-EW34

Volume Inj. : 1
Signal Phase : DB-5MS
Signal Info : 0.25



Data File : C:\HPCHEM\1\DATA\AUG04\040819\F1D6964.D

Vial: 7

Acq On : 8-19-04 15:14:37 PM

Operator: TT

Sample : C0809-10B X20

Inst : F1

Misc :

Multiplr: 1.00

IntFile : AUTOINT1.E

Quant Time: Aug 19 15:52 19104 Quant Results File: ET0304F.RES

Quant Method : C:\HPCHEM\1\QMETHODS\ET0304F.M (Chemstation Integrat

Title : TPH-GC, Fuel ID, DRO

Last Update : Fri Aug 13 08:50:23 2004

Response via : Multiple Level Calibration

DataAcq Meth : ETPH-B.M

D13222

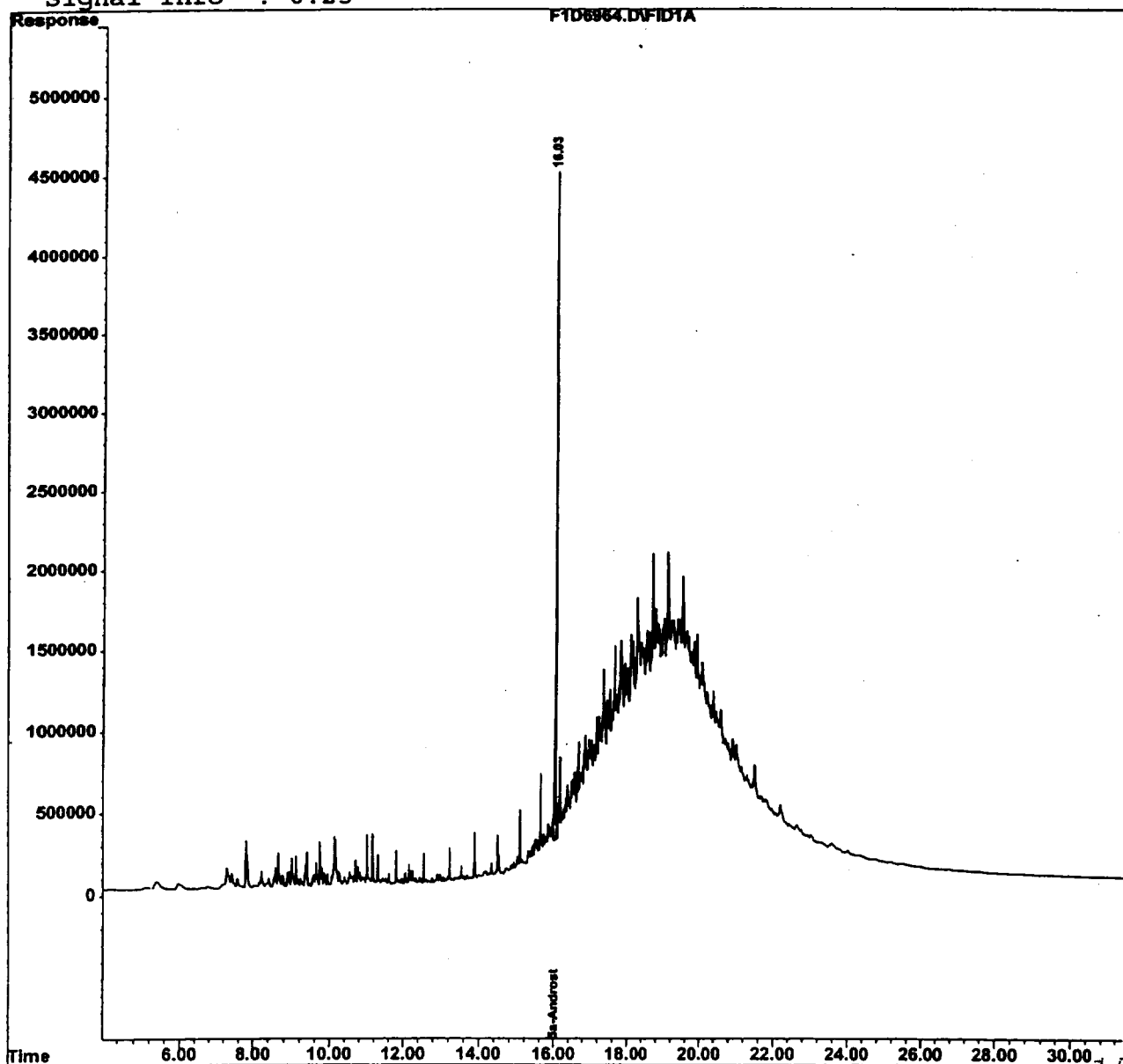
BW0-EMUL

-EW34

Volume Inj. : 1

Signal Phase : DB-5MS

Signal Info : 0.25



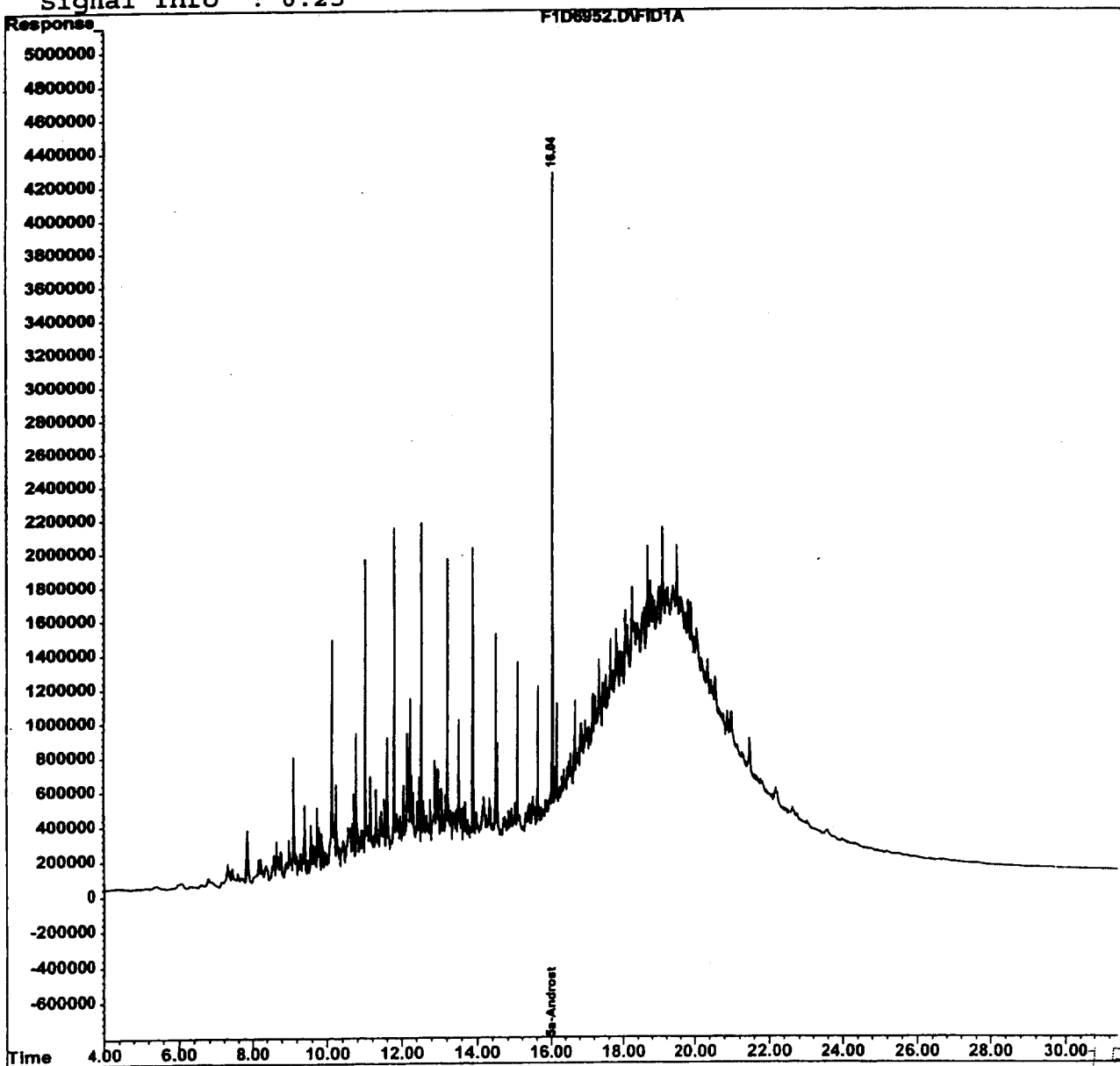
Quantitation Report

Data File : C:\HPCHEM\1\DATA\AUG04\040819\F1D6952.D Vial: 1
Acq On : 8-19-04 11:25:16 PM Operator: TT
Sample : C0809-04B X20 Inst : F1
Misc : Multiplr: 1.00
IntFile : AUTOINT1.E
Quant Time: Aug 19 14:31 19104 Quant Results File: ET0304F.RES

Quant Method : C:\HPCHEM\1\QMETHODS\ET0304F.M (Chemstation Integrator)
Title : TPH-GC, Fuel ID, DRO
Last Update : Fri Aug 13 08:50:23 2004
Response via : Multiple Level Calibration
DataAcq Meth : ETPH-B.M

Volume Inj. : 1
Signal Phase : DB-5MS
Signal Info : 0.25

D13216
BWD-014-EW94



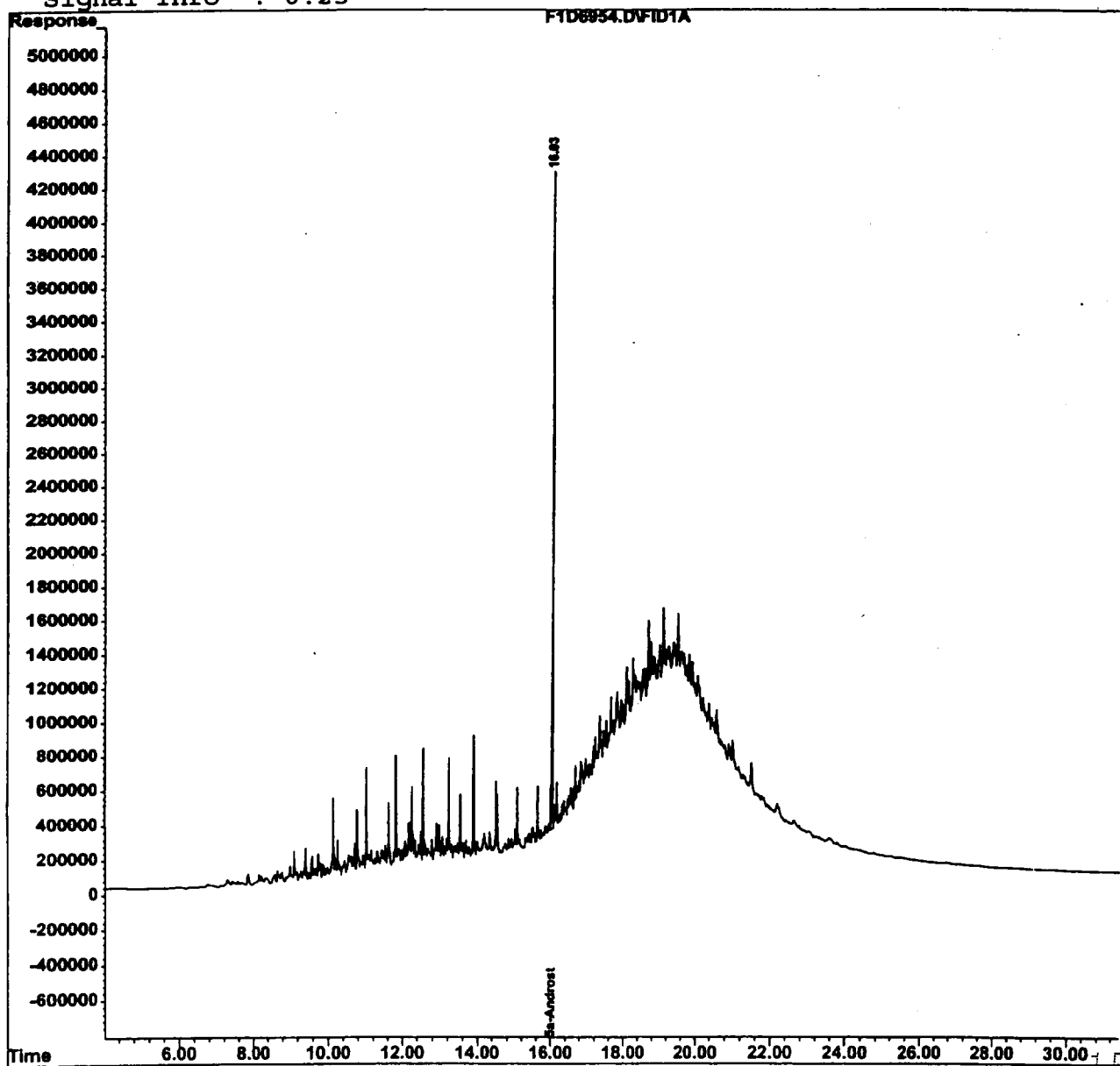
Quantitation Report

Data File : C:\HPCHEM\1\DATA\AUG04\040819\F1D6954.D Vial: 2
 Acq On : 8-19-04 12:03:29 PM Operator: TT
 Sample : C0809-05B X20 Inst : F1
 Misc : Multiplr: 1.00
 IntFile : AUTOINT1.E
 Quant Time: Aug 19 14:33 19104 Quant Results File: ET0304F.RES

Quant Method : C:\HPCHEM\1\QMETHODS\ET0304F.M (Chemstation Integrat
 Title : TPH-GC, Fuel ID, DRO
 Last Update : Fri Aug 13 08:50:23 2004
 Response via : Multiple Level Calibration
 DataAcq Meth : ETPH-B.M

D13217
 BW0-014-EW 189

Volume Inj. : 1
 Signal Phase : DB-5MS
 Signal Info : 0.25



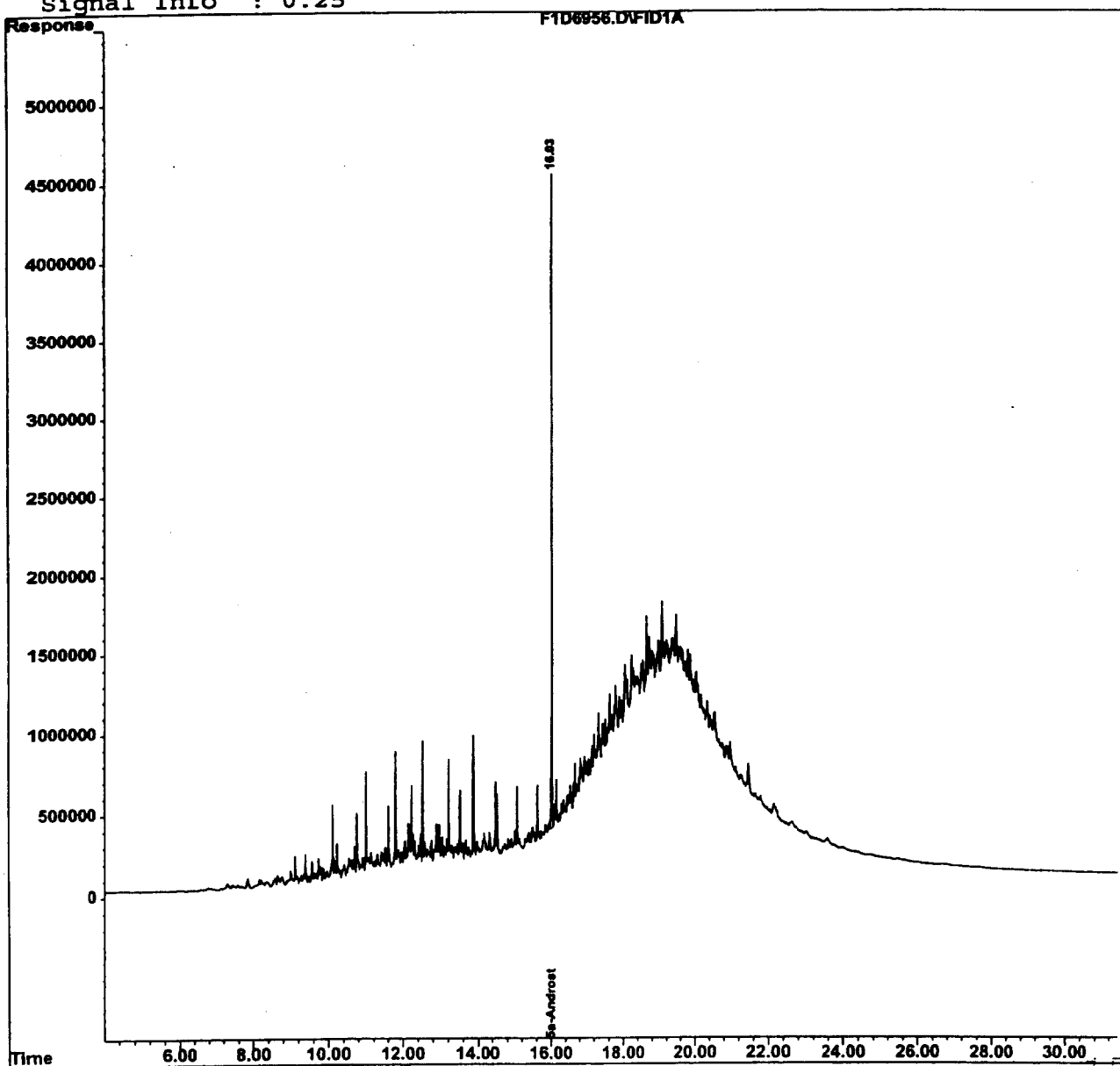
Quantitation Report

Data File : C:\HPCHEM\1\DATA\AUG04\040819\F1D6956.D Vial: 3
Acq On : 8-19-04 12:41:40 PM Operator: TT
Sample : C0809-06B X20 Inst : F1
Misc : Multiplr: 1.00
IntFile : AUTOINT1.E
Quant Time: Aug 19 14:35 19104 Quant Results File: ET0304F.RES

Quant Method : C:\HPCHEM\1\QMETHODS\ET0304F.M (Chemstation Integrator)
Title : TPH-GC, Fuel ID, DRO
Last Update : Fri Aug 13 08:50:23 2004
Response via : Multiple Level Calibration
DataAcq Meth : ETPH-B.M

D13218
BWO-EMUL-EW109

Volume Inj. : 1
Signal Phase : DB-5MS
Signal Info : 0.25



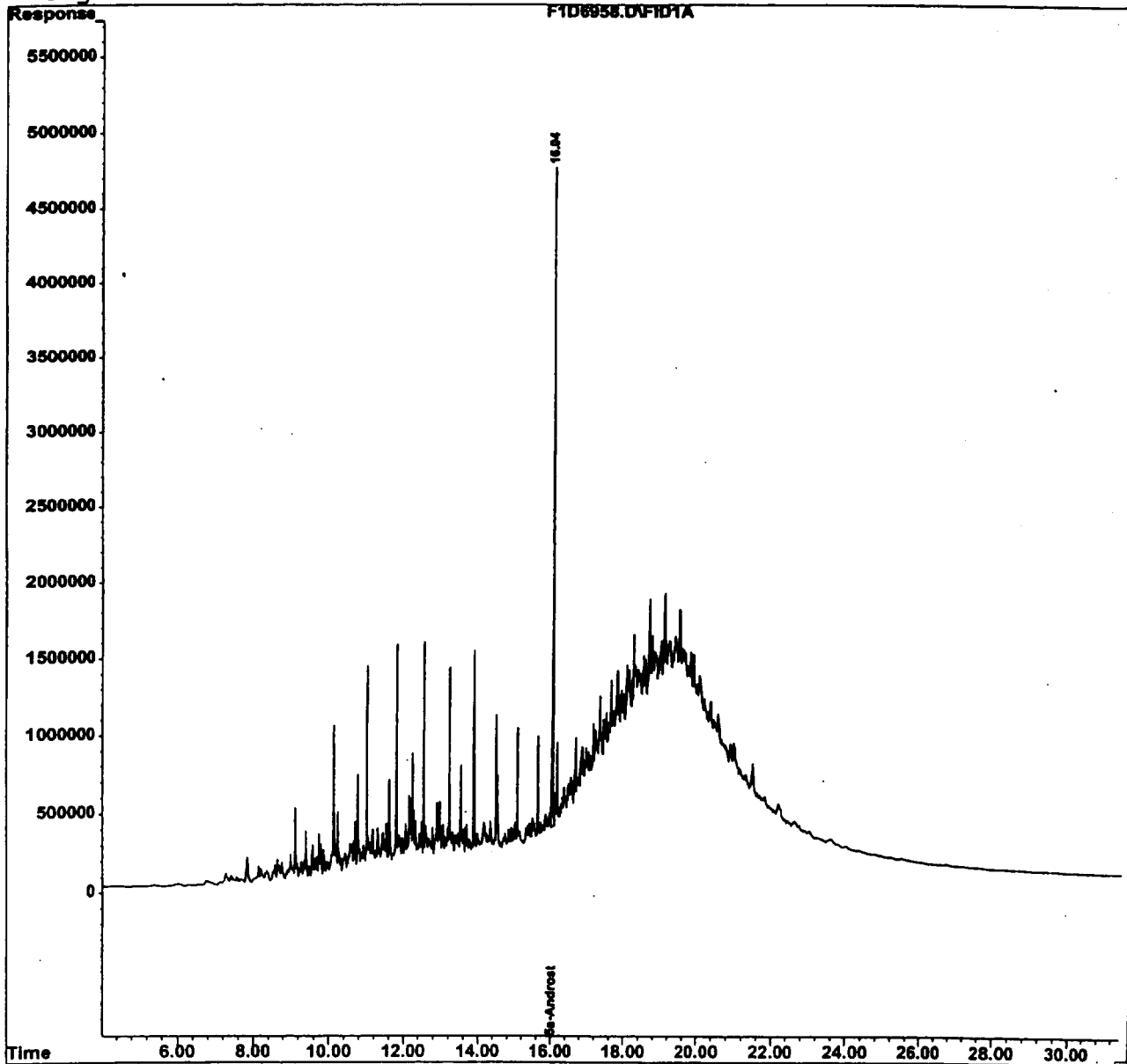
Quantitation Report

Data File : C:\HPCHEM\1\DATA\AUG04\040819\F1D6958.D Vial: 4
Acq On : 8-19-04 13:19:53 PM Operator: TT
Sample : C0809-07B X20 Inst : F1
Misc : Multiplr: 1.00
IntFile : AUTOINT1.E
Quant Time: Aug 19 14:38 19104 Quant Results File: ET0304F.RES

Quant Method : C:\HPCHEM\1\QMETHODS\ET0304F.M (Chemstation Integrat
Title : TPH-GC, Fuel ID, DRO
Last Update : Fri Aug 13 08:50:23 2004
Response via : Multiple Level Calibration
DataAcq Meth : ETPH-B.M

D13219
BW0-0IL-EW11

Volume Inj. : 1
Signal Phase : DB-5MS
Signal Info : 0.25



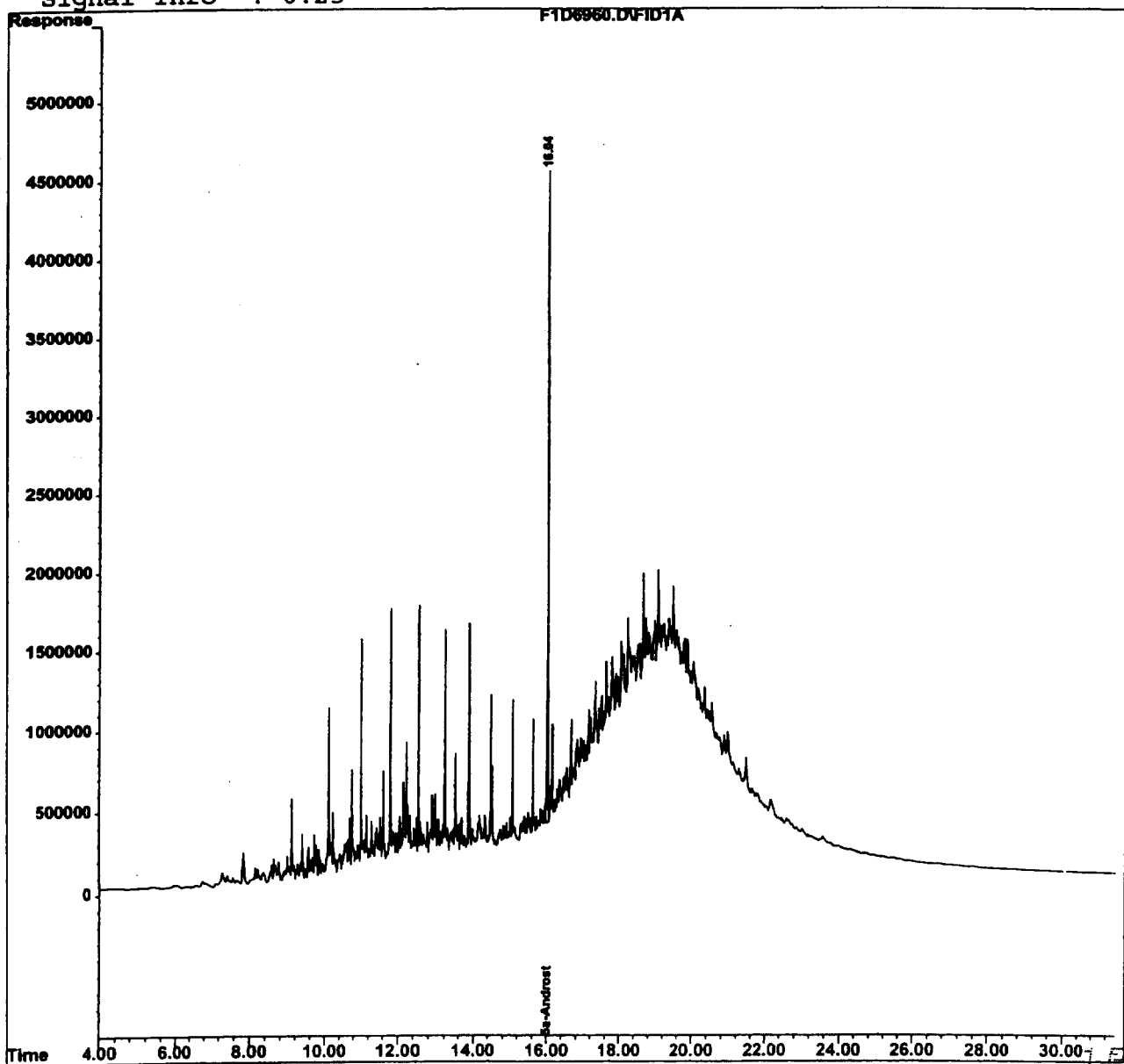
Quantitation Report

Data File : C:\HPCHEM\1\DATA\AUG04\040819\F1D6960.D Vial: 5
Acq On : 8-19-04 13:58:08 PM Operator: TT
Sample : C0809-08B X20 Inst : F1
Misc : Multiplr: 1.00
IntFile : AUTOINT1.E
Quant Time: Aug 19 14:40 19104 Quant Results File: ET0304F.RES

Quant Method : C:\HPCHEM\1\QMETHODS\ET0304F.M (Chemstation Integrator)
Title : TPH-GC, Fuel ID, DRO
Last Update : Fri Aug 13 08:50:23 2004
Response via : Multiple Level Calibration
DataAcq Meth : ETPH-B.M

D13220
BWO-EMUL-EW11

Volume Inj. : 1
Signal Phase : DB-5MS
Signal Info : 0.25



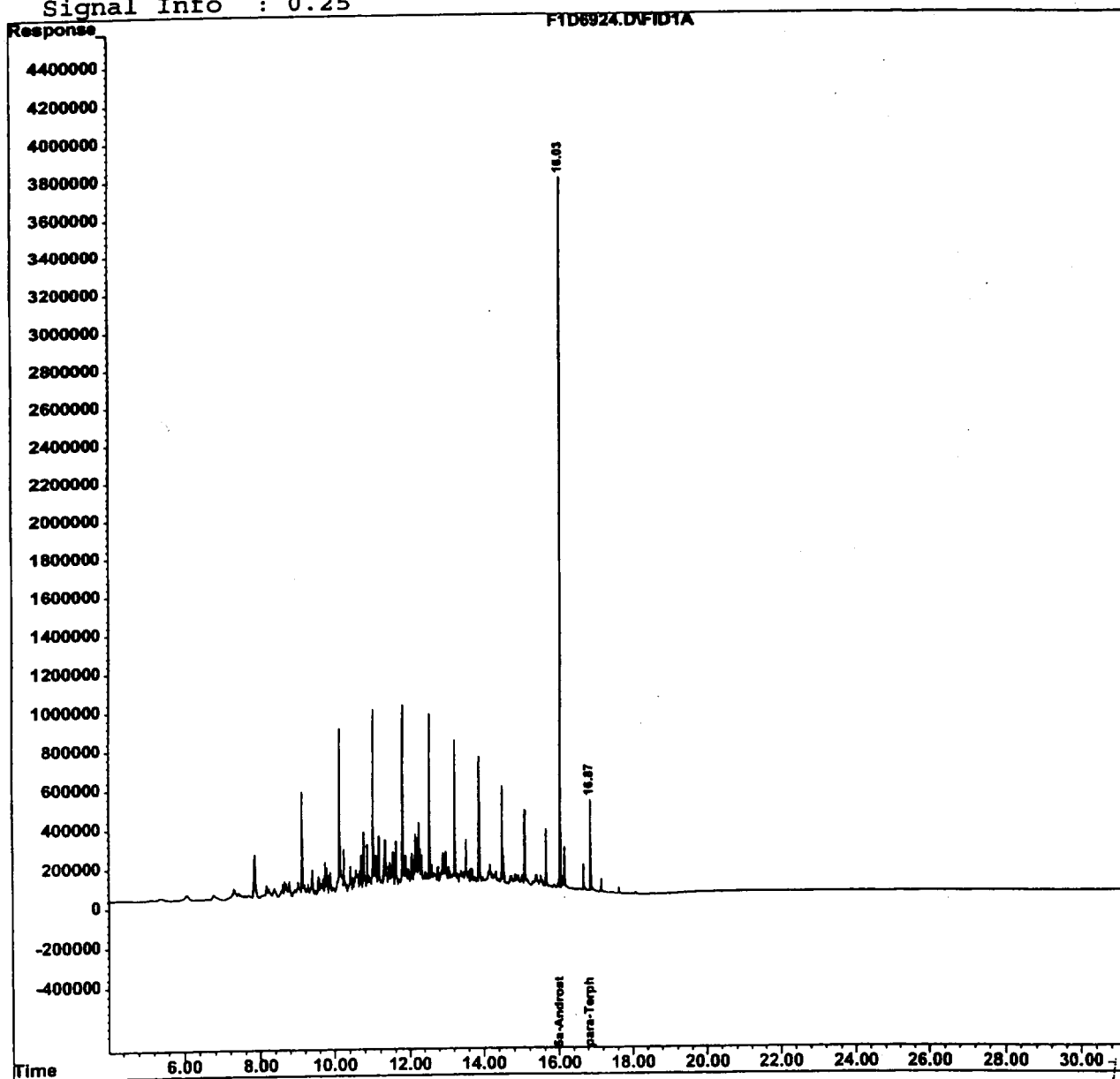
QUANTIFICATION REPORT

Data File : C:\HPCHEM\1\DATA\AUG04\040818\F1D6924.D Vial: 2
 Acq On : 8-18-04 20:54:55 PM Operator: TT
 Sample : LCS-14098 Inst : F1
 Misc : Multiplr: 1.00
 IntFile : AUTOINT1.E
 Quant Time: Aug 19 10:05 19104 Quant Results File: ET0304F.RES

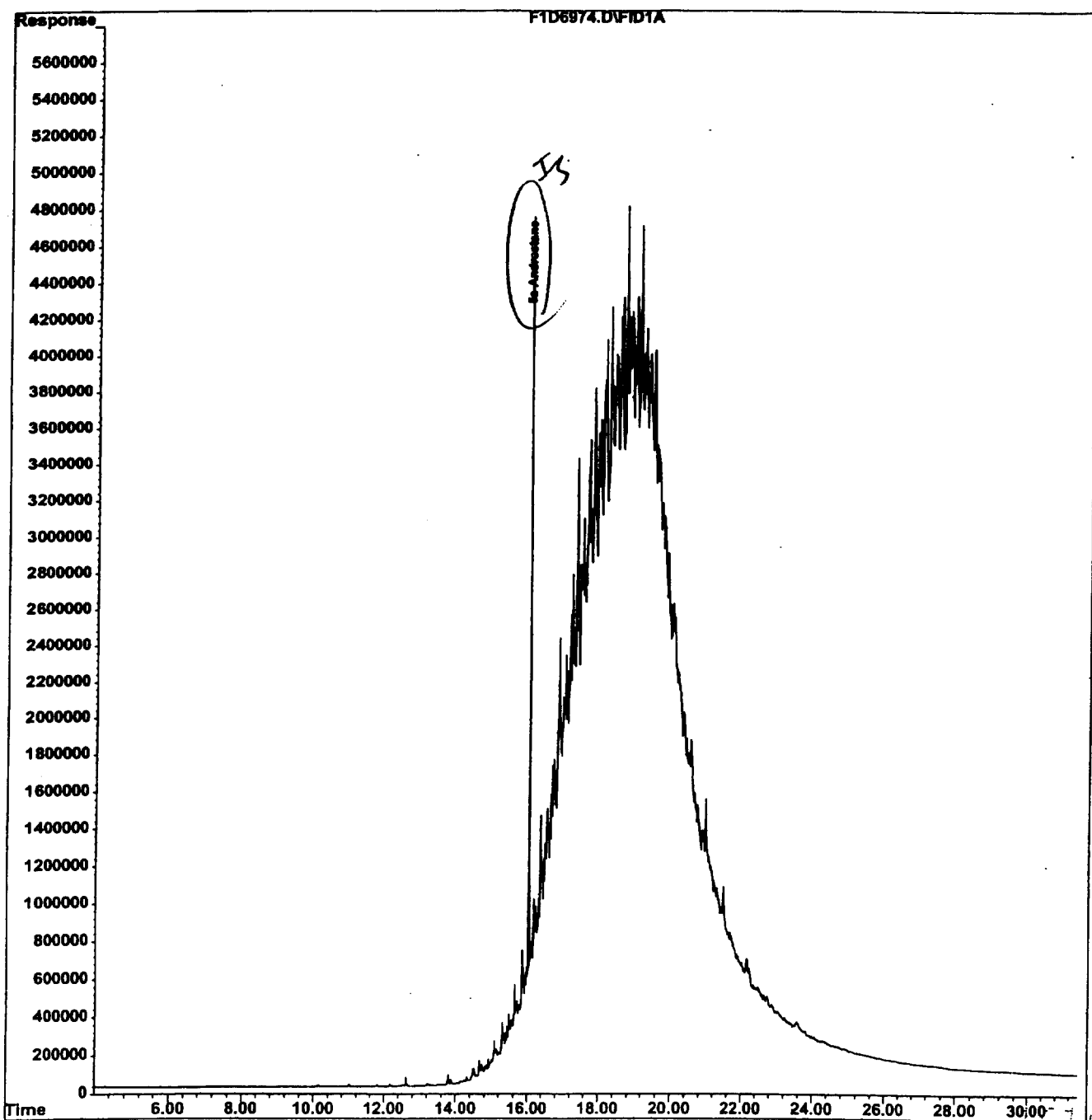
Quant Method : C:\HPCHEM\1\QMETHODS\ET0304F.M (Chemstation Integrat
 Title : TPH-GC, Fuel ID, DRO
 Last Update : Fri Aug 13 08:50:23 2004
 Response via : Multiple Level Calibration
 DataAcq Meth : ETPH-B.M

Volume Inj. : 1
 Signal Phase : DB-5MS
 Signal Info : 0.25

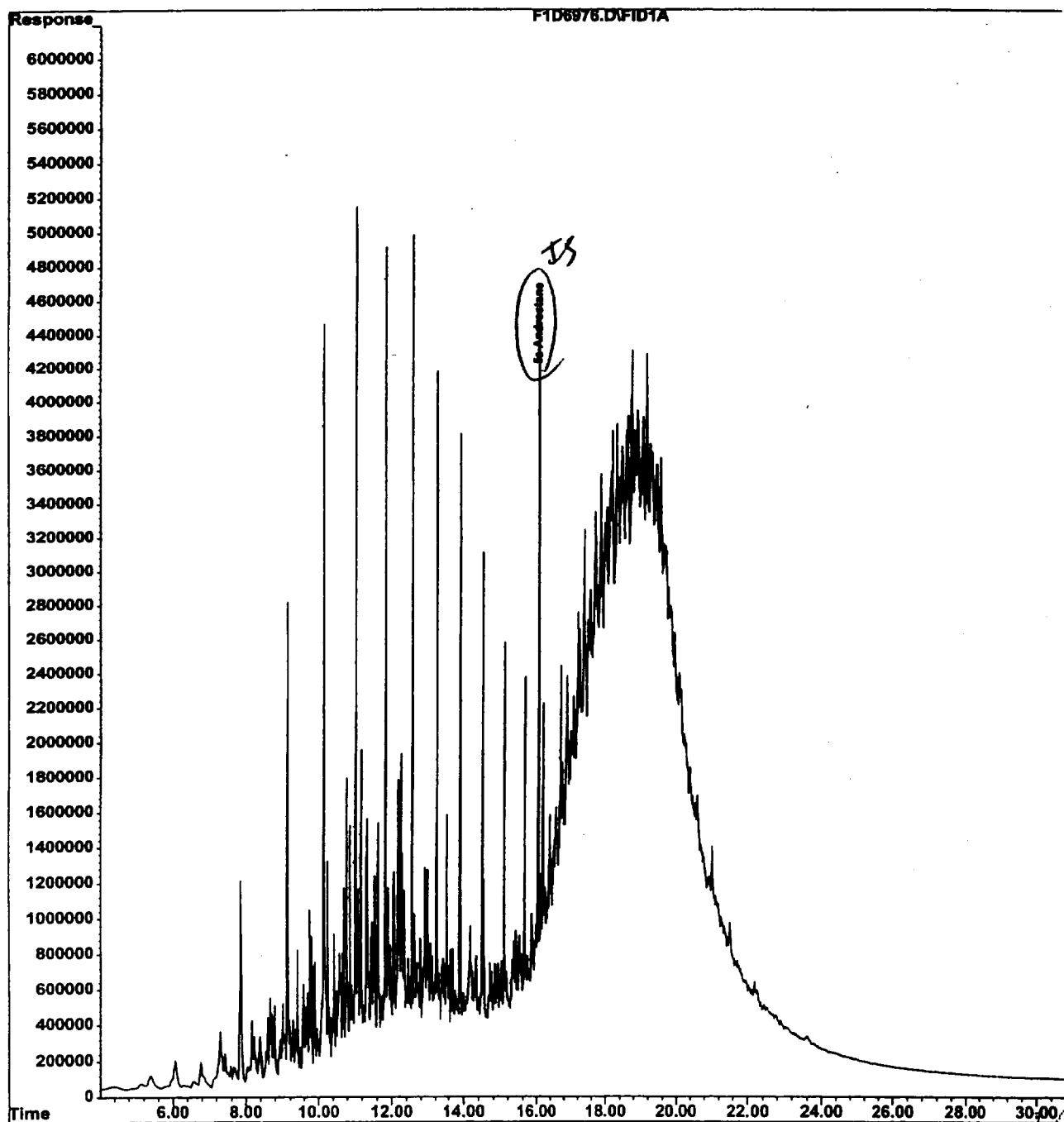
*Diesel No 2 fuel
 Standard*



File : C:\HPCHEM\1\DATA\AUG04\040819\F1D6974.D
Operator : TT
Acquired : 8-20-04 10:29:29 PM using AcqMethod ETPH-B.M
Instrument : F1
Sample Name: MOTOR OIL STANDARD
Misc Info : CITGO 10W-30
Vial Number: 2



File : C:\HPCHEM\1\DATA\AUG04\040819\F1D6976.D
Operator : TT
Acquired : 8-20-04 11:56:45 PM using AcqMethod ETPH-B.M
Instrument : F1
Sample Name: MOTOR OIL + DIESEL ST~~AND~~
Misc Info :
Vial Number: 3



APPENDIX B
LNAPL VOLUME CALCULATIONS – BACKUP INFORMATION

CALCULATION OF SITE-SPECIFIC LNAPL VOLUMES

SUMMARY OF INPUT PARAMETERS

Since sand is the dominant lithology, an average sand lithology was selected. Other data were considered and the following input data were utilized in the site-specific LNAPL calculations:

- Effective Porosity – 0.30, consistent with site soil types
- Hydraulic conductivity – 6.4 ft/day, average of geometric means of the three soil types
- van Genuchten alpha – average sand value from API and average value based on range of conductivities
- van Genuchten n – same as for alpha
- Residual water saturation – same as for alpha
- Surface tension – average of the 5 observed LNAPL types from API reference tables
- Interfacial tension - average of the 5 observed LNAPL types from API reference tables
- Dynamic viscosity – average of 9 values for “oil” from July 2004 LNAPL analyses
- Specific gravity - average of 9 values for “oil” from July 2004 LNAPL analyses

CALCULATION OF SITE-SPECIFIC LNAPL VOLUMES

EQUATIONS USED

All equations below are calculated as a function elevation (z)

Weight-height equivalent pressure head for water-phase	$h_w(z) = z_{aw} - z$
Water-height equivalent pressure for oil phase	$h_o(z) = \rho_{ro} * (z_{ao} - z)$
Air-oil phase capillary head	$h_{ao}(z) = \rho_{ro} * (z - z_{ao})$
Oil-water phase capillary head	$h_{ow}(z) = h_o(z) - h_w(z)$
van Genuchten parametric model for 2- and 3-phase saturation-pressure relation	$Sstar(h) = \text{if}[h > 0, [(1 + (\alpha * h)^n)^{-m}, 1]$
Effective water-phase saturation	$Sbar_w(z) = Sstar(\beta_{ow} * h_{ow}(z))$
Water-phase saturation	$S_w(z) = S_m + (1 - S_m) * Sbar_w(z)$
Effective total liquid saturation	$Sbar_l(z) = Sstar(\beta_{ow} * h_{ow}(z))$
Oil phase saturation (calculated in 2 steps to account for negative values)	$Stemp_o(z) = S_m - S_w(z) + (1 - S_m) * Sbar_l(z)$ $k_{temp}(z) = ((Sbar_l(z) - Sbar_w(z))^{1/5}) * [(1 - Sbar_w(z)^{(1/m)})^{1/m} - (1 - Sbar_l(z)^{(1/m)})^{1/m}]^2$
Upper limit for integration of NAPL volume (assumed to be air-oil interface)	$z_u = z_{ow} + D_0$
Indefinite integral equation for NAPL volume	$V(z) = \int \Phi * S_o(z) dz$
NAPL volume in soil	$V_o = V(z_u) - V(z_{ow})$
Relative permability of NAPL (step 1)	$k_{ro}(z) = \text{if}(Sbar_l(z) > Sbar_w(z), k_{temp}(z), 0)$
Indefinite integral equation for the relative permability of NAPL	$K_{ro}(z) = \int k_{ro}(z) dz$
Relative permability of NAPL	$K_{ro} = [1 / (z_u - z_{ow})] * (K_{ro}(z_u) - K_{ro}(z_{ow}))$

$S_o(z) = \text{if}(Stemp_o > 0, Stemp_o(z), 0)$

Source of Equations used:

Source: "Estimation of Free Hydrocarbon Volume From Fluid Levels in Monitoring Wells", by R.J. Lenhard and J.C. Parker, Ground Water, 28(1), 1990

INPUT PARAMETERS

Soil Parameters

Effective Porosity (ϕ)	0.500
Hydraulic conductivity (k_w) (ft/day)	1.00
van Genuchten parameter, α (1/ft)	1.00
van Genuchten parameter, n	2.00
Residual water saturation (S_{wr})	0.150
Irreducible Water Content (θ_{wr})	0.0

General constants

Surface tension of uncontaminated water (σ_{aw}) (dyne/cm)	72
Water Density (ρ_w) (lb/ft ³)	62.4
Dynamic viscosity of water (μ_w) (poise)	0.01
Acceleration due to gravity (g) (ft/s ²)	32.174

LNAPL Parameters

Surface Tension (σ_{so}) (dyn/cm)	27.15
Interfacial Tension (σ_{ow}) (dyn/cm)	48
Dynamic Viscosity (μ_o) (P)	0.7282
Specific Gravity (pro)	10.8715

Operational Data

Regional water table elevation (z_{aw}) (ft)	10
NAPL thickness in well (H_o) (ft)	0.5
Area of NAPL (A_N) (ft ²)	79660

NOTE

To calculate results, press enter, and then press Ctrl-n. The spreadsheet does not automatically calculate the results.

CALCULATIONS AND RESULTS

Parameter	Equation	Result
Van Genuchten parameter m	$m = 1 - 1/n$	0.627
NAPL density (ρ_o) (lb/ft ³)	$\rho_o = \rho_{ro} \cdot \rho_w$	54.400
Scaling coefficient air-oil (β_{ao})	$\beta_{ao} = \sigma_{aw} / \sigma_{ao}$	2.681
Scaling coefficient oil-water (β_{ow})	$\beta_{ow} = \sigma_{aw} / \sigma_{ow}$	1.514
Residual water saturation (S_m)	$S_m = \theta_{wr} / \Phi$	0.150
Elevation of air-oil interface (z_{ao}) (ft)	$z_{ao} = H_0 + z_{ow}$	110.064
Elevation of oil-water interface (z_{ow}) (ft)	$z_{ow} = z_{aw} - H_0 \cdot \rho_{ro}$	109.584
NAPL thickness in soil (D_o) (ft)	$D_o = (\rho_{ro} \cdot \beta_{ao} \cdot H_0) / (\beta_{ao} \cdot \rho_{ro} - \beta_{ow}(1 - \rho_{ro}))$	
Specific volume of NAPL in soil (V_o) (ft ³ /ft ²)	See included equations	
NAPL volume in soil (V) (ft ³)	$V = V_o \cdot A_N$	208.63
NAPL volume in soil (V) (Gal)	7.48 Gal / ft ³	
Permeability of NAPL relative to water	See included equations	2.5754E-03

INPUT PARAMETERS

Soil Parameters

Effective Porosity (Φ)	0.300
Hydraulic conductivity (k_w) (ft/day)	5.00
van Genuchten parameter, α (1/ft)	0.001
van Genuchten parameter, n	2.690
Residual water saturation (S_m)	0.150
Irreducible Water Content (θ_{wr})	0.02

General constants

Surface tension of uncontaminated water (σ_{sw}) (dyne/cm)	72.8
Water Density (ρ_w) (lb/ft ³)	62.4
Dynamic viscosity of water (μ_w) (poise)	0.01
Acceleration due to gravity (g) (ft/s ²)	32.174

LNAPL Parameters

Surface Tension (σ_{so}) (dyn/cm)	27.15
Interfacial Tension (σ_{ow}) (dyn/cm)	48.1
Dynamic Viscosity (μ_o) (P)	0.7262
Specific Gravity (pro)	0.8718

Operational Data

Regional water table elevation (z_{sw}) (ft)	110
NAPL thickness in well (H_o) (ft)	15
Area of NAPL (A_N) (ft ²)	18200

NOTE

To calculate results, press enter, and then press Ctrl-n. The spreadsheet does not automatically calculate the results.

CALCULATIONS AND RESULTS

Parameter	Equation	Result
Van Genuchten parameter m	$m = 1 - 1/n$	0.627
NAPL density (ρ_o) (lb/ft ³)	$\rho_o = \rho_{ro} \cdot \rho_w$	54.400
Scaling coefficient air-oil (β_{ao})	$\beta_{ao} = \sigma_{aw} / \sigma_{ao}$	2.681
Scaling coefficient oil-water (β_{ow})	$\beta_{ow} = \sigma_{aw} / \sigma_{ow}$	1.514
Residual water saturation (S_m)	$S_m = \theta_w / \Phi$	0.150
Elevation of air-oil interface (z_{ao}) (ft)	$z_{ao} = H_o + z_{ow}$	110.192
Elevation of oil-water interface (z_{ow}) (ft)	$z_{ow} = z_{aw} - H_o \cdot \rho_{ro}$	108.692
NAPL thickness in soil (D_o) (ft)	$D_o = (\rho_{ro} \cdot \beta_{ao} \cdot H_o) / (\beta_{ao} \cdot \rho_{ro} \cdot \beta_{ow} (1 - \rho_{ro}))$	
Specific volume of NAPL in soil (V_o) (ft ³ /ft ²)	See included equations	
NAPL volume in soil (V) (ft ³)	$V = V_o \cdot A_N$	1486.24
NAPL volume in soil (V) (Gal)	7.48 Gal / ft ³	
Permeability of NAPL relative to water	See included equations	1.2226E-01

INPUT PARAMETERS

Soil Parameters

Effective Porosity (Φ)	0.300
Hydraulic conductivity (k_w) (ft/day)	0.000
van Genuchten parameter, α (1/ft)	1.400
van Genuchten parameter, n	2.500
Residual water saturation (S_m)	0.150
Irreducible Water Content (θ_w)	0.000

General constants

Surface tension of uncontaminated water (σ_{sw}) (dyne/cm)	72.0
Water Density (ρ_w) (lb/ft ³)	62.4
Dynamic viscosity of water (μ_w) (poise)	0.0131
Acceleration due to gravity (g) (ft/s ²)	32.174

LNAPL Parameters

Surface Tension (σ_{so}) (dyn/cm)	27.0
Interfacial Tension (σ_{ow}) (dyn/cm)	48.1
Dynamic Viscosity (μ_o) (P)	0.7262
Specific Gravity (ρ_{ro})	0.8718

Operational Data

Regional water table elevation (z_{sw}) (ft)	110.0
NAPL thickness in well (H_o) (ft)	5.0
Area of NAPL (A_n) (ft ²)	1000

NOTE

To calculate results, press enter, and then press Ctrl-n. The spreadsheet does not automatically calculate the results.

CALCULATIONS AND RESULTS

Parameter	Equation	Result
Van Genuchten parameter m	$m = 1 - 1/n$	0.627
NAPL density (ρ_o) (lb/ft ³)	$\rho_o = \rho_{ro} \cdot \rho_w$	54.400
Scaling coefficient air-oil (β_{ao})	$\beta_{ao} = \sigma_{aw} / \sigma_{ao}$	2.681
Scaling coefficient oil-water (β_{ow})	$\beta_{ow} = \sigma_{aw} / \sigma_{ow}$	1.514
Residual water saturation (S_m)	$S_m = \theta_w / \Phi$	0.150
Elevation of air-oil interface (z_{ao}) (ft)	$z_{ao} = H_o + z_{ow}$	110.385
Elevation of oil-water interface (z_{ow}) (ft)	$z_{ow} = z_{aw} - H_o \cdot \rho_{ro}$	107.385
NAPL thickness in soil (D_o) (ft)	$D_o = (\rho_{ro} \cdot \beta_{ao} \cdot H_o) / (\beta_{ao} \cdot \rho_{ro} - \beta_{ow}(1 - \rho_{ro}))$	
Specific volume of NAPL in soil (V_o) (ft ³ /ft ²)	See included equations	
NAPL volume in soil (V) (ft ³)	$V = V_o \cdot A_N$	2493.60
NAPL volume in soil (V) (Gal)	7.48 Gal / ft ³	
Permeability of NAPL relative to water	See included equations	3.7104E-01

API Model

van Genuchten-Mualem Model of LNAPL Distribution and Relative Permeability

Enter Data in Yellow Region

Maximum Monitoring Well LNAPL Thickness [feet]	
$b_o =$	3.000

Soil Characteristic		
$n =$	0.300	porosity
$N =$	2.680	van Genuchten "N"
$\alpha =$	4.400	van Genuchten " α " [ft ⁻¹]
$S_{WT} =$	0.150	irreducible water saturation
$S_{orv} =$	0.050	residual LNAPL saturation (vadose)
$S_{ors} =$	0.050	residual LNAPL saturation (saturated)

Fluid Characteristics:		
$\rho_o =$	0.872	LNAPL density [gm/cc]
$\sigma_{aw} =$	72.800	air/water surface tension [dyne/cm]
$\sigma_{ao} =$	72.800	air/LNAPL surface tension [dyne/cm]
$\sigma_{ow} =$	48.100	LNAPL/water surface tension [dyne/cm]

Calculated Parameters		
$M =$	0.827	van Genuchten "M"
$\alpha_{ao} =$	3.836	air/LNAPL " α " [ft ⁻¹]
$\alpha_{ow} =$	0.854	LNAPL/water " α " [ft ⁻¹]
$z_{ao} =$	0.385	elevation of air-LNAPL interface [ft]
$z_{ow} =$	-2.615	elevation of LNAPL-water interface [ft]
$z_{max} =$	1.245	maximum free-product elevation [ft]
$\lambda =$	1.124	pore-size distribution index
$\psi_b =$	0.148	B-C displacement pressure head [ft]

Set Tools > Option > Calculations tab to "Manual."

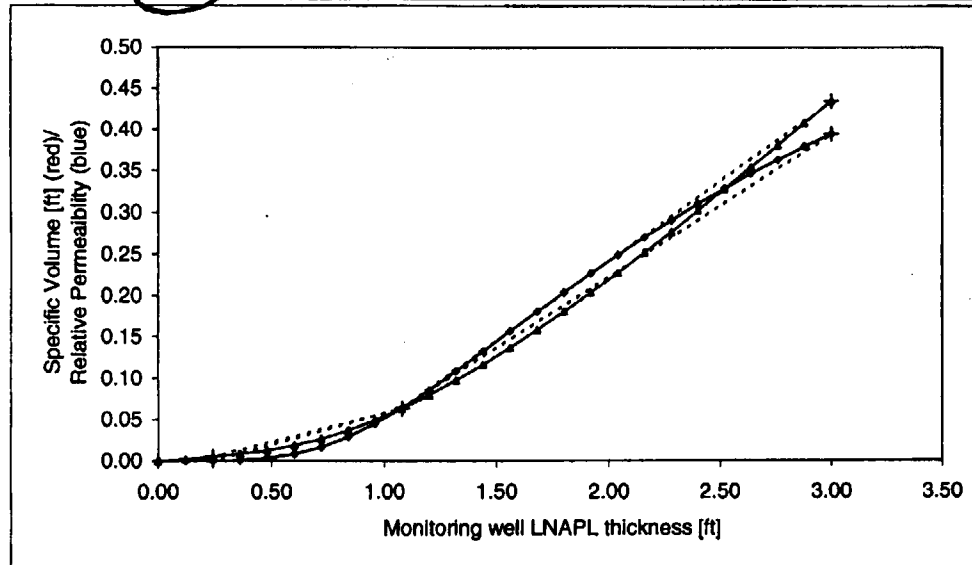
Press Ctrl+Shift+S to calculate sheet

(c) 2003 American Petroleum Institute. Duplication or retransmission of this workbook without the express authorization of the Institute is prohibited.

→ Publication # 4729, August 2003

b_0 [ft]	D_0 [ft]	$K_{0.05}$	χ [ft]	β	ϵ [ft]	η
0.000	0.000	0.000				
0.240	0.005	0.000				
1.080	0.082	0.084				
3.000	0.435	0.395				

0.0001	Eps-Do
0.0001	Eps-kro



$$\text{Specific Volume} = 0.435 \text{ ft}^3/\text{ft}^2$$

NapL in Soil =

$$\frac{0.435 \text{ ft}^3}{\text{ft}^2} \times 7000 \text{ ft}^2 = 3045 \text{ ft}^3$$

$$3045 \text{ ft}^3 = 22,778 \text{ gallons}$$

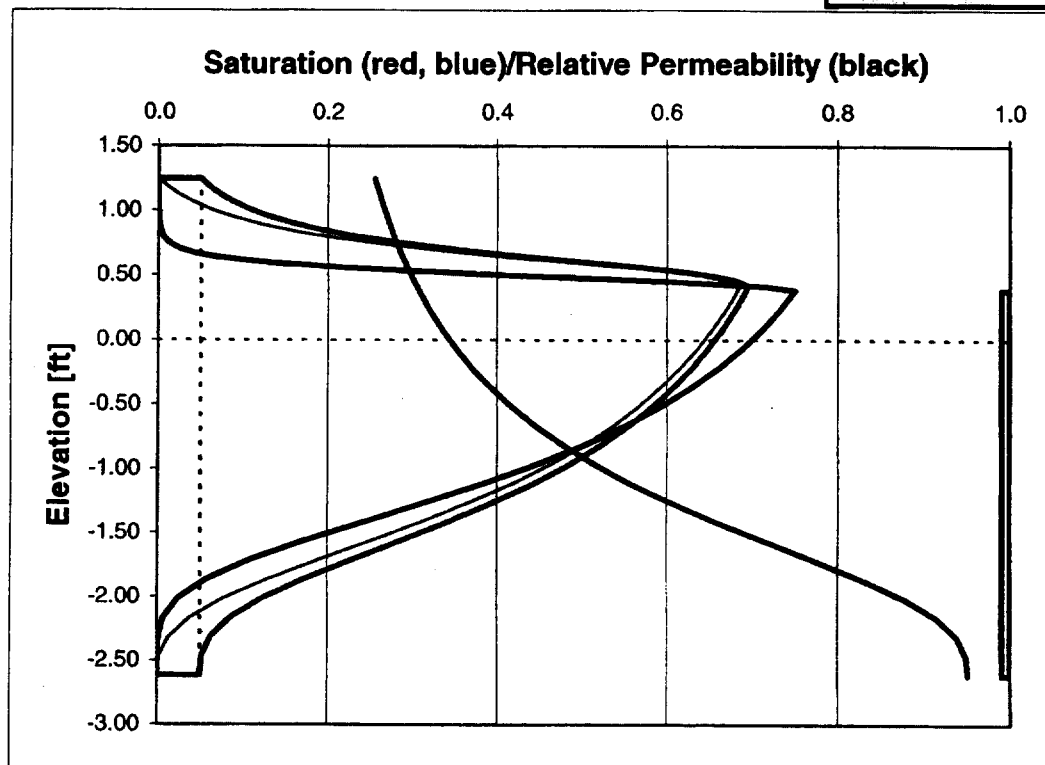
* Lenhard-Parker, basis of my LNAPL Volume calculations, determines 18,653 gallons

~ 18% Difference

Monitoring Well LNAPL Thickness b_o [ft] = 3.000 D_o [ft] = 0.435 k_o = 0.395

Enter b_o value
here to plot
corresponding
profiles

Press Ctrl+Shift+S to calculate sheet



INPUT PARAMETERS

Soil Parameters

Effective Porosity (Φ)	0.300
Hydraulic conductivity (k_w) (ft/day)	8.000
van Genuchten parameter, α (1/ft)	0.500
van Genuchten parameter, n	1.910
Residual water saturation (S_m)	0.379
Irreducible Water Content (θ_{wr})	0.114

General constants

Surface tension of uncontaminated water (σ_{aw}) (dyne/cm)	72.8
Water Density (ρ_w) (lb/ft ³)	62.4
Dynamic viscosity of water (μ_w) (poise)	0.01
Acceleration due to gravity (g) (ft/s ²)	32.172

LNAPL Parameters

Surface Tension (σ_{so}) (dyn/cm)	27.15
Interfacial Tension (σ_{ow}) (dyn/cm)	18.1
Dynamic Viscosity (μ_o) (P)	0.7262
Specific Gravity (ρ_{ro})	0.8718

Operational Data

Regional water table elevation (z_{aw}) (ft)	10
NAPL thickness in well (H_o) (ft)	3
Area of NAPL (A_N) (ft ²)	7000

NOTE

To calculate results, press enter, and then press Ctrl-n. The spreadsheet does not automatically calculate the results.

Beede - Average van G parameters from Conductivity Ranges from API Database

CALCULATIONS AND RESULTS

Parameter	Equation	Result
Van Genuchten parameter m	$m = 1 - 1/n$	0.476
NAPL density (ρ_0) (lb/ft ³)	$\rho_0 = \rho_{ro} \cdot \rho_w$	54.400
Scaling coefficient air-oil (β_{ao})	$\beta_{ao} = \sigma_{aw} / \sigma_{ao}$	2.681
Scaling coefficient oil-water (β_{ow})	$\beta_{ow} = \sigma_{aw} / \sigma_{ow}$	1.514
Residual water saturation (S_m)	$S_m = \theta_w / \Phi$	0.379
Elevation of air-oil interface (z_{ao}) (ft)	$z_{ao} = H_0 + z_{ow}$	110.385
Elevation of oil-water interface (z_{ow}) (ft)	$z_{ow} = z_{aw} - H_0 \cdot \rho_{ro}$	107.385
NAPL thickness in soil (D_0) (ft)	$D_0 = (\rho_{ro} \cdot \beta_{ao} \cdot H_0) / (\beta_{ao} \cdot \rho_{ro} - \beta_{ow}(1 - \rho_{ro}))$	
Specific volume of NAPL in soil (V_0) (ft ³ /ft ²)	See included equations	
NAPL volume in soil (V) (ft ³)	$V = V_0 \cdot A_N$	84.81
NAPL volume in soil (V) (Gal)	7.48 Gal / ft ³	
Permeability of NAPL relative to water	See included equations	7.5173E-03